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## TECHNICAL NOTE 4284

CUMULATIVE FATIGUE DAMAGE AT ELEVATED TEMPERATURE

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SUMMARY

A study of cumulative fatigue damage at elevated temperatures was conducted using heat-treated SAE 4130 alloy steel. The S-N curves at room temperature, $400^\circ$ F, and $800^\circ$ F were obtained from rotating-beam fatigue tests. Two-step, three-step, and five-step cumulative-damage fatigue tests were conducted on rotating-beam fatigue specimens at room temperature, $400^\circ$ F, and $800^\circ$ F. The results of the cumulative-damage tests are compared with those of a theoretical analysis.

INTRODUCTION

The behavior of a material subjected to repeated applications of load is of importance in the structural design of aircraft. Consequently, investigators have compiled volumes of data on the fatigue properties of aircraft materials and the effect of numerous variables on these properties. Most of these data were obtained by repeatedly applying a constant amplitude of alternating stress to a specimen until failure occurred. By testing a number of specimens at different stress levels, an S-N curve is obtained in which stress is plotted against cycles to failure.

The data obtained from conventional fatigue tests at constant stress amplitudes are of questionable value for design applications in which the maximum intensity of stress is not constant during the life of the structure. This problem is of particular interest in aircraft design since the stresses produced by air loads, gust loads, engine vibrations, and landings vary in magnitude and duration. The problem is further complicated by the fact that repeated stressing of a material at one stress amplitude may have pronounced effects on the fatigue properties at other stress amplitudes.

A number of investigations have been conducted (refs. 1 to 17) to determine the effect of stressing a material at one stress amplitude on the fatigue life at a second stress amplitude. The evidence indicates that for both ferrous and aluminum alloys understressing, overstressing, and coaxing may produce considerable change in the fatigue properties

of a material.  There have been attempts to explain these effects as the result of cold-working, strain-aging, residual stresses, and specimen selectivity.  None of these explanations appear to be adequate since they fail to account completely for all the experimental evidence.

Additional investigations have been conducted (refs. 18 to 22) in which the stress amplitude was varied according to some definite, usually periodic, program during the test.  The results of tests of this type are difficult to interpret for design purposes unless the test load was varied in the same manner as that in which the load will vary in the part being designed.  Since there are an infinite number of possible service stress histories, the accumulation of data in this manner would appear to be an endless task.

In order to obtain a rational design procedure it is necessary first to establish a hypothesis of fatigue damage.  It appears reasonable to assume that a material subjected to repeated stressing undergoes some damage during each cycle of stress and that this damage accumulates to the point of failure.  With such a hypothesis it is possible to relate the behavior of a material subjected to cycles of varying stress amplitude to its behavior when subjected to cycles of constant stress amplitude.  It is then possible to design a member that will be subjected to varying stress amplitudes during its life by use of the conventional S-N curve and the loading spectrum for the member (refs. 20 and 23 to 25).

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## SYMBOLS

D          fatigue damage

E          endurance limit

k          constant

N          number of loading cycles to failure at stress  S

n          number of loading cycles applied at stress  S

R          cycle ratio, $\dfrac{n}{N}$

S          stress

W          net work absorbed at failure or work done to failure

$$\gamma = \frac{S - E}{E}$$

Subscripts:

1, 2, . . . n    indicates steps or levels

## CUMULATIVE-DAMAGE STUDIES

Miner (ref. 26) proposed the first usable hypothesis of fatigue damage by relating damage at each stress amplitude to the net work that may be absorbed by a material. Miner assumed that fatigue damage could be expressed as the ratio of the number of loading cycles applied at a given stress to the number of cycles required to produce failure at the given stress. This ratio is referred to as the cycle ratio. Miner further assumed that if a material was subjected to repeated loading at more than one stress amplitude failure would occur when the sum of the cycle ratios became unity. This simple concept of cumulative damage may be expressed symbolically as follows: If

W            net work absorbed at failure or work done to failure

$W_1$         work absorbed at stress $S_1$ in $n_1$ cycles

$n_1$         number of loading cycles applied at stress $S_1$

$N_1$         number of loading cycles to failure at stress $S_1$

$R_1$         cycle ratio at stress $S_1$

then, the first assumption may be expressed as

$$\frac{W_1}{W} = \frac{n_1}{N_1} = R_1$$

and the second assumption may be expressed as

$$W_1 + W_2 + W_3 + \ . \ . \ . \ W_n = W$$

or

$$\frac{W_1}{W} + \frac{W_2}{W} + \frac{W_3}{W} + \ldots \frac{W_n}{W} = 1$$

from which

$$\frac{n_1}{N_1} + \frac{n_2}{N_2} + \frac{n_3}{N_3} + \ldots \frac{n_n}{N_n} = 1$$

or

$$R_1 + R_2 + R_3 + \ldots R_n = 1$$

The last equation which may be expressed as $\sum \frac{n}{N} = 1$ is frequently referred to as Miner's sum or the cumulative cycle ratio.

To verify this hypothesis, Miner performed a series of 22 axial-load fatigue tests on sheet specimens and riveted specimens of 2024-T3 alclad aluminum. Individual specimens were each subjected to two, three, or four different stress amplitudes. The average value of the cumulative cycle ratio was 1.015 with a minimum of 0.61 and a maximum of 1.45. Although the average value of the cumulative cycle ratio is very nearly unity as predicted by Miner's theory, the experimental evidence is not conclusive because of the relatively small number of tests and the scatter of the data.

Further investigations have shown that there are a number of additional factors not considered by Miner that influence fatigue damage. For example, it has been shown that regardless of whether a high or low stress is applied first, the number of different stress amplitudes applied and the magnitude of each stress level relative to the endurance limit are among the variables affecting fatigue damage.

Brueggeman, Mayer, and Smith (ref. 27) conducted a series of axial-load tests on 93 specimens of 2024-T3 aluminum-alloy sheet containing a drilled hole. All specimens were subjected to two-step tests in which a given number of cycles were applied at one stress followed by stressing at a second stress until failure. When the initial stress was less than the second stress, the cumulative cycle ratio at failure exceeded unity. When the initial stress was greater than the second stress, the cumulative cycle ratio was less than unity.

Bennett (ref. 10) performed a series of tests on SAE 4130 steel using both axial load and rotating bending machines. His results with respect to the effect of the sequence in which the stresses are applied are identical to those of Brueggeman, Mayer, and Smith.

Richart and Newmark (ref. 28) have proposed a hypothesis in which the effect of the sequence in which the stresses are applied is considered. If fatigue damage is denoted by the term D, curves of cycle ratio against damage may be plotted. It is assumed that the damage is zero before applying any stresses and unity when a specimen has failed because of repeated stressing. Points on the conventional S-N curve represent a cycle ratio of unity and a damage of unity. As a material is subjected to repeated stressing the cycle ratio increases and the damage increases. However, the exact relationship between cycle ratio and damage is not known.

Miner assumed a linear relationship between cycle ratio and damage as shown by the line $D = R$ in figure 1. Richart and Newmark assume that the relation between cycle ratio and damage is a function of the stress as shown by the curves $S_1$, $S_2$, and $S_3$ in figure 1 in which $S_1 > S_2 > S_3$. The assumption of Richart and Newmark agrees with the experimental evidence which indicates that at low stress levels a relatively small amount of damage occurs during the early cycles but increases rapidly toward the end of the endurance lift. On the other hand, at high stress levels a greater amount of damage occurs during the early cycles than during the latter stages. This assumption agrees with the conclusions of other investigators that the cumulative cycle ratio at failure is greater than unity when the initial stress is less than the final stress and less than unity when the initial stress is larger than the final stress.

In order to apply the hypothesis of Richart and Newmark it is necessary to determine experimentally curves of damage plotted against cycle ratio for various stresses in addition to the conventional S-N curve. Since curves of damage plotted against cycle ratio are not readily available for most materials, it would be difficult to use this procedure in design.

Grover, Bishop, and Jackson (ref. 29) conducted a number of two-step cumulative-damage axial-load fatigue tests on sheet specimens of 2024-T3 aluminum alloy, 7075-T6 aluminum alloy, and SAE 4130 steel. For the tests in which the low stress was applied first, the cumulative cycle ratio at failure exceeded unity for all three materials. For the tests in which the high stress was applied first, the cumulative cycle ratio at failure was less than unity for the SAE 4130 steel specimens. However, the tests on the aluminum-alloy specimens in which the high stress was applied first had a cumulative cycle ratio at failure greater than unity.

Marco and Starkey (ref. 30) reported a number of rotating-beam fatigue tests of 76S-T61 aluminum alloy and SAE 4340 steel in which cumulative damage was studied. The results of these tests also show the effect of the order in which the stresses are applied. During the course of each test the stress was changed 2, 4, 6, 10, 15, or 20 times. There was no well-defined effect due to the number of different stresses applied.

A very extensive axial-load cumulative-fatigue-damage study of alclad 7075-T6 and alclad 2024-T3 aluminum-alloy sheet was conducted by Smith, Howard, and Smith (ref. 31). A total of 805 specimens were tested under various loading conditions with all the cumulative-damage tests being two-step tests. Seventy-two percent of the average cumulative cycle ratios were within 20 percent of unity and 40 percent were within 10 percent of unity. The smallest average cumulative cycle ratio of a group of four similar specimens was 0.568 and the largest, 1.440. There was no systematic variation of the cumulative cycle ratio with the stress amplitude, the sheet thickness, the mean stress, or the alloy used.

Schijue and Jacobs (refs. 32) reported a number of cumulative-damage axial-load fatigue tests on both notched and unnotched specimens of 2024-T3 alclad. Considerable scatter in the results makes interpretation difficult. For example, in one series of 10 identical tests on notched specimens in which the high stress was applied first, the cumulative cycle ratio at failure varied from 0.19 to more than 18.

Low (ref. 33) conducted a number of reversed-bending cumulative-damage tests on aluminum-alloy sheet. Instead of the conventional S-N curve, a curve of maximum fiber strain plotted against number of cycles to failure was obtained which was similar in shape to the conventional S-N curve for nonferrous materials. In the cumulative-damage tests, the value of the cumulative cycle ratio at failure varied from 0.75 to 1.49. A plot of the maximum fiber strain against the number of cycles to failure at the final strain is linear which suggests another variable that may influence the value of the cumulative cycle ratio.

Henry (ref. 34) has made a theoretical analysis of fatigue-damage accumulation based on the assumption that the S-N curve may be represented by the equation $N = \dfrac{k}{S - E}$ where $k$ is a constant and $E$ is the endurance limit. An expression denoted by $\gamma$ is called the overstress ratio and defined as

$$\gamma = \frac{S - E}{E}$$

Henry assumes that as a material accumulates fatigue damage the values of $k$ and $E$ change so that after a material has accumulated a certain amount of fatigue damage it has an S-N curve different from the S-N curve of the virgin material. Using these assumptions, Henry has derived the following expression for the fatigue damage $D$ (where $R$ is cycle ratio):

$$D = \frac{R}{1 + \frac{1 - R}{\gamma}}$$

Using this expression Henry has analyzed the experimental data of Bennett (ref. 10) and Kommers (refs. 9). There is close agreement between the experimental results and the results predicted by Henry's theory. Henry's theory may be applied to predict the cumulative cycle ratio when only the conventional S-N curves of a material are available.

All the fatigue-damage tests reported in the literature were conducted at room temperature. The present investigation was undertaken to determine the fatigue-damage characteristics of a typical aircraft steel at elevated temperatures.

MATERIAL

The material used in this investigation was supplied as 225 feet of $\frac{1}{2}$ - inch-diameter round rod from one heat of SAE 4130 steel which was heat-treated to military specification S 6758, condition F5.

The chemical analysis was as follows:

Carbon, percent by weight . . . . . . . . . . . . . . . . . . . . . . . . 0.33
Manganese, percent by weight . . . . . . . . . . . . . . . . . . . . . . 0.46
Phosphorus, percent by weight . . . . . . . . . . . . . . . . . . . . . . 0.014
Sulphur, percent by weight . . . . . . . . . . . . . . . . . . . . . . . . 0.010
Silicon, percent by weight . . . . . . . . . . . . . . . . . . . . . . . . 0.30
Nickel, percent by weight . . . . . . . . . . . . . . . . . . . . . . . . 0.17
Chromium, percent by weight . . . . . . . . . . . . . . . . . . . . . . . 0.90
Molybdenum, percent by weight . . . . . . . . . . . . . . . . . . . . . . 0.20

The room-temperature mechanical properties were determined using American Society for Metals standard 5/16-inch tension specimens. These tests were performed in a Baldwin 60,000-pound universal testing machine with Huggenberger Tensometers used to measure strains. The average room-temperature mechanical properties from six tests were as follows:

Ultimate strength, psi . . . . . . . . . . . . . . . . . . . . . .        133,800
Proportional limit, psi . . . . . . . . . . . . . . . . . . . . .         80,000
Yield strength (0.2-percent offset), psi . . . . . . . . . .              111,300
Young's modulus, psi . . . . . . . . . . . . . . . . . . . . . .       30,040,000
Elongation in 1 inch, percent . . . . . . . . . . . . . . . .                 26
Reduction of area, percent . . . . . . . . . . . . . . . . . .              65.7
Rockwell hardness . . . . . . . . . . . . . . . . . . . . . . .            C26.3

The average tensile stress-strain curve is shown in figure 2.

## APPARATUS AND PROCEDURE

For comparison purposes, a series of cumulative fatigue tests were conducted at room temperature using a Krouse rotating bending fatigue machine operating at 4,800 rpm.

The elevated-temperature tests were conducted in a Krouse high-speed, high-temperature, repeated-stress machine at a testing speed of 4,800 rpm. This machine is described in detail in reference 35.

The dimensions of the specimens used for all the fatigue tests are given in figure 3. The specimens were machined from the $\frac{1}{2}$ - inch-diameter rod and then polished. The machining marks were removed with 120-grit Metalite cloth and 280-grit Metalite cloth was used for the final polish. All circumferential scratches were removed by polishing parallel to the longitudinal axis of the specimen while it was slowly rotated in a lathe. Approximately 0.002 inch of the material was removed in the polishing operation.

For the elevated-temperature tests the specimens were inserted in the furnace at room temperature and rotated at zero stress while the furnace temperature was increased to the test temperature. The testing temperature was obtained in approximately 45 minutes. After reaching the test temperature an additional 15 minutes was allowed to obtain temperature equilibrium before applying the load.

To obtain the S-N curve at each temperature, a series of conventional fatigue tests were performed. A minimum of four specimens were tested at each of 10 different stress levels.

The cumulative-damage tests at each temperature were conducted in three parts: A series of two-step tests, a series of three-step tests, and a series of five-step tests.

The two-step tests were conducted according to the following schedule:

(1) Initial stress $S_1$ less than final stress $S_2$
    (a) Cycle ratio of 0.25 at $S_1$ to failure at $S_2$
    (b) Cycle ratio of 0.50 at $S_1$ to failure at $S_2$
    (c) Cycle ratio of 0.75 at $S_1$ to failure at $S_2$

(2) Initial stress $S_1$ greater than final stress $S_2$
    (a) Cycle ratio of 0.25 at $S_1$ to failure at $S_2$
    (b) Cycle ratio of 0.50 at $S_1$ to failure at $S_2$
    (c) Cycle ratio of 0.75 at $S_1$ to failure at $S_2$

A minimum of four specimens were tested in each stress sequence. The entire schedule was then repeated for a different set of stresses $S_1$ and $S_2$.

The three-step tests were conducted according to the following schedule:

(1) Stress level progressively increasing, $S_1 < S_2 < S_3$:
    Cycle ratio of 0.30 at $S_1$ followed by cycle ratio of 0.30 at $S_2$ to failure at $S_3$

(2) Stress level progressively decreasing, $S_1 > S_2 > S_3$:
    Cycle ratio of 0.30 at $S_1$ followed by cycle ratio of 0.30 at $S_2$ to failure at $S_3$

A minimum of four specimens were tested in each sequence.

The five-step tests were conducted according to the following schedule:

(1) Stress level progressively increasing, $S_1 < S_2 < S_3 < S_4 < S_5$
(2) Stress level progressively decreasing, $S_1 > S_2 > S_3 > S_4 > S_5$
(3) Stress level alternating, $S_1 < S_2$, $S_2 > S_3$, $S_3 < S_4$, $S_4 > S_5$

A cycle ratio of 0.20 was applied at each of the first four stress levels followed by stressing until failure at the final stress level. A minimum of four specimens were tested in each sequence.

## RESULTS AND DISCUSSION

### Room Temperature

The data used to obtain the S-N curve at room temperature are summarized in table I. The mean S-N curve shown in figure 4 was obtained by the method of reference 36, as illustrated in appendix A. The reasonable range (ref. 36) of the mean S-N curve is ±300 psi. For a single specimen, the average value of cycle ratio $\frac{n}{N}$ was 1.035 with a minimum value of 0.780 and a maximum value of 1.343. Seventy-five percent of the specimens had a value of $\frac{n}{N}$ within 15 percent of unity and 61 percent of the specimens had a value of $\frac{n}{N}$ within 10 percent of unity.

The results of the two-step tests at room temperature are summarized in table II. For 24 specimens to which the low stress was applied first, the average value of the cumulative cycle ratio at failure was 1.169. For 24 specimens to which the high stress was applied first, the average value of the cumulative cycle ratio was 0.809.

The results of the three-step tests at room temperature are given in table III. For the specimens for which the stress level was progressively increased during the test, the average value of the cumulative cycle ratio was 1.644. For the specimens for which the stress level was progressively decreased during the test, the average value of the cumulative cycle ratio was 0.787.

The results of the five-step tests at room temperature are summarized in table IV. When the stress level was progressively increased the average value of the cumulative cycle ratio was 1.107. When the stress level was progressively decreased the average value of the cumulative cycle ratio was 0.875. For specimens for which the stress level was alternately increased and decreased, the average cumulative cycle ratio was 0.846.

As other investigations have shown, the data given in tables II, III, and IV indicate that at room temperature the order in which the stresses are applied affects the cumulative cycle ratio. In general, when a low stress is applied first, the damage at the low stress is less

than that predicted by Miner and when a high stress is applied first the damage is greater than that predicted.

Henry (ref. 34) considered the effect of the order in which the stresses are applied in developing his theory. For each of the cumulative-damage tests, the theoretical cumulative cycle ratio has been computed using Henry's theory and compared with the experimental results in table V. A sample computation using Henry's theory is given in appendix B. In general, the test results at room temperature show close agreement with the values predicted by Henry.

## Temperature, $400^\circ$ F

The test results used to obtain the mean S-N curve at $400^\circ$ F are presented in tabular form in table VI and shown graphically in figure 5. The reasonable range of the mean curve is $\pm 730$ psi. For a single specimen, the average value of $\frac{n}{N}$ was 1.016 with a minimum value of 0.465 and a maximum value of 1.595. Fifty-one percent of the specimens had a value of $\frac{n}{N}$ within 15 percent of unity and 41 percent of the specimens had a value of $\frac{n}{N}$ within 10 percent of unity. The scatter is somewhat larger than that found in the room-temperature tests. This greater scatter may be attributed to the introduction of the temperature variable.

The results of the two-step tests at $400^\circ$ F are presented in tables VII and VIII. In table VII the cycle ratio was computed using the mean S-N curve whereas in table VIII the computations were based on the minimum S-N curve. The computations based on the minimum S-N curve are presented to show that, in the cumulative-damage tests, the range of values obtained for the cumulative cycle ratio cannot be explained solely on the basis of scatter. Table VIII shows that the cumulative cycle ratio is less than unity when the high stress is applied first even when the computations are based on the minimum fatigue life. Table VIII also shows that if the computations are based on the minimum S-N curve the effect of the order in which the stresses are applied is the same at elevated temperature as it is at room temperature. For specimens to which the low stress was applied first the average value of the cumulative cycle ratio was 1.283. For specimens to which the high stress was applied first the average value of the cumulative cycle ratio was 0.848.

Tables IX and X present the results of three-step tests at $400^\circ$ F. Based on the minimum S-N curve, the average value of the cumulative cycle ratio was 1.862 for specimens subjected to progressively increasing

stresses and 0.865 for specimens subjected to progressively decreasing stresses.

The results of the five-step tests at 400° F are given in tables XI and XII. Based on the minimum curve, the average value of the cumulative cycle ratio was 2.456 for specimens subjected to progressively increasing stresses and 1.128 for specimens on which the stress level was alternately increased and decreased.

In table XIII the experimental results are compared with the results predicted by Henry's theory. All the computations in this table are based on the minimum fatigue life. Although the agreement is not so close as that at room temperature, Henry's theory appears to predict satisfactorily the effect of stress sequence on the cumulative cycle ratio.

## Temperature, 800° F

The test results used to obtain the mean S-N curve at 800° F are presented in tabular form in table XIV and shown graphically in figure 6. The reasonable range of the mean curve is ±410 psi. For a single specimen, the average value of $\frac{n}{N}$ was 1.161 with a minimum value of 0.345 and a maximum value of 2.567. Although this represents greater scatter than the room-temperature tests or the tests at 400° F, the reasonable range of the mean curve is less because of the larger number of specimens tested. Only 20 percent had a value of $\frac{n}{N}$ within 20 percent of unity and 15 percent of the specimens had a value of $\frac{n}{N}$ within 10 percent of unity.

The results of the two-step tests at 800° F are presented in table XV. For 27 specimens to which the low stress was applied first, the average value of the cumulative cycle ratio at failure was 1.302. For 26 specimens to which the high stress was applied first, the average value of the cumulative cycle ratio at failure was 0.594. The effect of the order in which the stresses were applied is the same as that noted at room temperature and at 400° F.

Table XVI presents the results of the three-step tests at 800° F. For the specimens on which the stress level was progressively increased during the test, the average value of the cumulative cycle ratio at failure was 0.584. For specimens on which the stress level was progressively decreased during the test, the average value of the cumulative cycle ratio at failure was 0.450. These data again indicate the effect of the order of application of stress on the cumulative cycle ratio at

failure. However, in the progressively increasing stress tests, the cumulative cycle ratio was not greater than unity.

In table XVII, the results of the five-step tests at 800° F are given. The average value of the cumulative cycle ratio at failure was 0.884 for specimens subjected to progressively increasing stresses, 0.459 for specimens subjected to progressively decreasing stresses, and 0.379 for specimens on which the stress level was alternately increased and decreased. As in the three-step tests, the cumulative cycle ratio at failure was less than unity regardless of the order in which the stresses were applied.

The comparison of the experimental results at 800° F with those obtained by Henry's theory is given in table XVIII. Although Henry's theory appears to predict the proper trend, the agreement is not close in the progressively increasing three-step and five-step tests.

CONCLUDING REMARKS

A study of cumulative fatigue damage at elevated temperatures using heat-treated SAE 4130 alloy steel has been made. In using fatigue data, it is important to recognize that the fatigue curve represents only average values. An individual specimen may exhibit a fatigue life considerably different from the average. The data obtained indicate that fatigue testing at elevated temperatures may be expected to result in even greater scatter than that which appears at room temperature. When this already large scatter is coupled with further inaccuracies introduced by testing at more than one stress level, the scatter may become large enough to overshadow the effects of the variables being studied. However, the results indicate that the frequently accepted assumption that damage is proportional to cycle ratio errs on the unsafe side under certain conditions. These results cannot be explained solely on the basis of scatter.

Since Henry (Transactions of A.S.M.E., August 1955) assumed an equation for the S-N curve that does not fit the elevated-temperature data, closer agreement may be obtained by the use of a different equation in the analysis.

The analysis developed by Henry satisfactorily predicts the cumulative cycle ratio at failure in room-temperature tests. At elevated temperatures, further study is indicated to arrive at a satisfactory analysis.

University of Alabama,
    University, Ala., March 25, 1957.

APPENDIX A


METHOD FOR OBTAINING MEAN S-N CURVE


In order to obtain the mean life at each stress amplitude, the mean
S-N curve was determined by the method proposed in reference 36. This
method assumes that fatigue data follow a normal distribution on the
stress scale which has been shown to be reasonably correct (ref. 37).
The mean S-N curve is established by a statistical technique through
trial and error. To illustrate this method, a portion of the room-
temperature data has been replotted in figure 7.

Groups of points are selected so that each group contains at least
5 test points within a 10 to 1 life scatter. The data plotted in fig-
ure 7 have been divided into two groups denoted A and B. After selecting
the groups, the center of each group is determined by inspection and the
vertical lines TT' drawn through the center. The center of each group
represents the approximate mean-log-life of the group.

The mean stress of each group at the mean life is then determined.
For each plotted point, the vertical displacement from the estimated
curve is measured and expressed in terms of stress. In figure 7, the
vertical displacement of one of the points in group A is shown as
$\Delta S = 1,500$ psi. This displacement is considered positive when the point
lies above the curve. The algebraic sum and the mean of these vertical
displacements are then computed for each group. For group A, the alge-
braic sum is given by

$$\sum (\Delta S) = 700 + 500 - 500 - 1,100 + 1,500 + 1,100 + 0 - 450 = 1,750 \text{ psi}$$

and the mean stress is $\dfrac{1,750}{8} = 219$ psi.

The mean is then measured off on line TT' from points z to w.
Point w lies above the curve when the mean is positive and below the
curve when the mean is negative. The mean of each group is computed
and a new curve, shown in figure 7 as the corrected curve, is drawn
through the points labeled w in each group.

In reference 36 it is recommended that the entire procedure be
repeated until the stresses of any curve are within 2 percent of the
stress of the preceding curve. The final curve obtained is the mean
curve. The reasonable range is defined as

$$\pm \frac{2C}{\sqrt{N}}\,\sigma$$

where

N                number of specimens

$$C = \sqrt{\frac{N}{2}} \times \frac{\left(\dfrac{N-3}{2}\right)!}{\left(\dfrac{N-2}{2}\right)!}$$

$\sigma$            uncorrected standard deviation, $\sqrt{\displaystyle\sum_{i=1}^{N} \frac{\left(X_i - \overline{X}\right)^2}{N}}$

$X_i - \overline{X}$    vertical displacement of any point from corrected mean curve

For the room-temperature data, the standard deviation of the 41 specimens was 945 psi and the reasonable range ±302 psi. This indicates that the probable position of the real mean curve is within ±302 psi of the position shown in figure 4.

APPENDIX B


EXAMPLE OF COMPUTATION OF CUMULATIVE CYCLE RATIO


To illustrate the method of analysis proposed by Henry, the computation of the theoretical cumulative cycle ratio is carried out in detail for one specimen at room temperature.

Assume that a specimen is to be subjected to a cycle ratio $R_1$ of 0.250 at a stress $S_1$ of 80,000 psi followed by stressing at $S_2$ of 88,000 psi until failure. From figure 4 the endurance limit $E$ at room temperature is 77,000 psi. The overstress ratio at $S_1$ is given by

$$\gamma_1 = \frac{S_1 - E}{E} = \frac{80,000 - 77,000}{77,000} = 0.039$$

The overstress ratio at $S_2$ is

$$\gamma_2 = \frac{S_2 - E}{E} = \frac{88,000 - 77,000}{77,000} = 0.143$$

The damage due to imposing a cycle ratio of 0.250 at $S_1$ is

$$D_1 = \frac{R_1}{1 + \dfrac{1 - R_1}{\gamma_1}} = \frac{0.250}{1 + \dfrac{0.750}{0.039}} = 0.012$$

The damage due to stressing at $S_1$ represents a cycle ratio at $S_2$ equal to

$$R_2 = \frac{D_1\left(1 + \gamma_2\right)}{D_1 + \gamma_2} = \frac{0.012(1.143)}{0.012 + 0.143} = 0.090$$

The life remaining at $S_2$ is $\left(1 - R_2\right)$ or 0.910. The cumulative cycle ratio is the result of a cycle ratio of 0.250 at $S_1$ plus a cycle ratio of 0.910 at $S_2$. Therefore,

$$\sum \frac{n}{N} = 0.250 + 0.910 = 1.160$$

As shown in table II, the average experimental value obtained for this condition was 1.134.

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TABLE I.- RESULTS OF ROOM-TEMPERATURE TESTS AT ONE STRESS LEVEL

[N obtained from mean S-N curve]

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F75 | 98,000 | 28,700 | 33,500 | 0.857 | 10.4 |
| 12F76 | 98,000 | 30,700 | 33,500 | .916 | 4.3 |
| 12F80 | 98,000 | 34,200 | 33,500 | 1.021 | 6.7 |
| 12F74 | 98,000 | 34,600 | 33,500 | 1.033 | 7.9 |
| | | | | Av. .957 | Av. ±7.3 |
| 12F63 | 94,000 | 50,000 | 53,500 | .935 | 12.2 |
| 12F67 | 94,000 | 53,300 | 53,500 | .996 | 6.5 |
| 12F64 | 94,000 | 60,300 | 53,500 | 1.127 | 5.8 |
| 12F65 | 94,000 | 64,300 | 53,500 | 1.202 | 12.9 |
| | | | | Av. 1.065 | Av. ±9.4 |
| 12F61 | 90,000 | 67,100 | 86,000 | .780 | 9.3 |
| 12F62 | 90,000 | 73,400 | 86,000 | .853 | .8 |
| 12F59 | 90,000 | 75,000 | 86,000 | .872 | 1.4 |
| 12F60 | 90,000 | 80,200 | 86,000 | .933 | 8.4 |
| | | | | Av. .860 | Av. ±5.0 |
| 12F72 | 88,000 | 105,300 | 110,000 | .957 | 14.1 |
| 12F79 | 88,000 | 110,200 | 110,000 | 1.002 | 10.1 |
| 12F71 | 88,000 | 132,200 | 110,000 | 1.202 | 7.8 |
| 12F78 | 88,000 | 142,200 | 110,000 | 1.293 | 16.5 |
| | | | | Av. 1.114 | Av. ±12.1 |
| 12F2 | 85,000 | 138,000 | 158,000 | .873 | 17.6 |
| 12F4 | 85,000 | 164,500 | 158,000 | 1.041 | 1.7 |
| 12F5 | 85,000 | 173,000 | 158,000 | 1.095 | 3.3 |
| 12F3 | 85,000 | 193,600 | 158,000 | 1.225 | 15.7 |
| | | | | Av. 1.059 | Av. ±9.6 |
| 12F9 | 84,000 | 170,100 | 173,000 | 983 | 3.6 |
| 12F11 | 84,000 | 173,800 | 173,000 | 1.005 | 1.5 |
| 12F6 | 84,000 | 175,800 | 173,000 | 1.016 | .4 |
| 12F10 | 84,000 | 186,200 | 173,000 | 1.076 | 5.5 |
| | | | | Av. 1.020 | Av. ±2.8 |

TABLE I.- RESULTS OF ROOM-TEMPERATURE TESTS AT

ONE STRESS LEVEL - Concluded

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F12 | 82,000 | 225,000 | 224,000 | 1.004 | 6.3 |
| 12F13 | 82,000 | 244,000 | 224,000 | 1.091 | 1.9 |
| 12F15 | 82,000 | 244,800 | 224,000 | 1.093 | 2.1 |
| 12F14 | 82,000 | 245,500 | 224,000 | 1.096 | 2.3 |
|  |  |  |  | Av. 1.071 | Av. ±3.2 |
| 12F17 | 80,000 | 228,000 | 282,000 | .809 | 18.1 |
| 12F19 | 80,000 | 270,500 | 282,000 | .959 | 3.0 |
| 12F18 | 80,000 | 276,400 | 282,000 | .980 | .8 |
| 12F16 | 80,000 | 339,200 | 282,000 | 1.203 | 21.8 |
|  |  |  |  | Av. .988 | Av. ±10.9 |
| 12F23 | 78,000 | 396,300 | 410,000 | .967 | 18.3 |
| 12F25 | 78,000 | 444,300 | 410,000 | 1.084 | 8.5 |
| 12F21 | 78,000 | 549,600 | 410,000 | 1.340 | 13.2 |
| 12F22 | 78,000 | 550,600 | 410,000 | 1.343 | 13.4 |
|  |  |  |  | Av. 1.184 | Av. ±13.4 |
| 12F28 | 77,000 | 495,900 | (a) |  |  |
| 12F30 | 77,000 | 537,100 | (a) |  |  |
| 12F29 | 77,000 | 1,001,000 | (a) |  |  |
| 12F81 | 77,000 | 11,793,700 | (a b) |  |  |
| 12F27 | 77,000 | 12,404,800 | (a b) |  |  |

[a]Stress corresponds to endurance limit.
[b]Specimen did not fail.

TABLE II.- RESULTS OF TWO-STEP TESTS AT ROOM TEMPERATURE

[From mean curve: N at 80,000 psi is 282,000 cycles, N at 82,000 psi
is 224,000 cycles, N at 88,000 psi is 110,000 cycles, and N at
94,000 psi is 53,500 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F90 | 80,000 | 88,000 | 0.250 | 0.935 | 1.185 | 4.5 |
| 12F119 | 80,000 | 88,000 | .250 | .833 | 1.083 | 5.5 |
| 12F120 | 80,000 | 88,000 | .250 | .749 | .999 | 12.0 |
| 12F122 | 80,000 | 88,000 | .250 | 1.018 | 1.268 | 11.8 |
| | | | | | Av. 1.134 | Av. ±8.5 |
| 12F123 | 80,000 | 88,000 | .500 | .934 | 1.434 | 3.2 |
| 12F124 | 80,000 | 88,000 | .500 | .935 | 1.435 | 3.1 |
| 12F125 | 80,000 | 88,000 | .500 | .997 | 1.497 | 1.1 |
| 12F131 | 80,000 | 88,000 | .500 | 1.061 | 1.561 | 5.4 |
| | | | | | Av. 1.481 | Av. ±3.2 |
| 12F127 | 80,000 | 88,000 | .750 | .794 | 1.544 | 12.4 |
| 12F128 | 80,000 | 88,000 | .750 | .792 | 1.542 | 12.2 |
| 12F132 | 80,000 | 88,000 | .750 | .364 | 1.114 | 18.9 |
| 12F133 | 80,000 | 88,000 | .750 | .547 | 1.297 | 5.6 |
| | | | | | Av. 1.374 | Av. ±12.3 |
| 12F134 | 88,000 | 80,000 | .250 | .545 | .795 | 7.4 |
| 12F135 | 88,000 | 80,000 | .250 | .567 | .817 | 10.4 |
| 12F136 | 88,000 | 80,000 | .250 | .369 | .619 | 16.4 |
| 12F138 | 88,000 | 80,000 | .250 | .488 | .738 | .3 |
| | | | | | Av. .740 | Av. ±8.6 |
| 12F139 | 88,000 | 80,000 | .500 | .136 | .631 | 23.9 |
| 12F140 | 88,000 | 80,000 | .500 | .347 | .847 | 2.2 |
| 12F174 | 88,000 | 80,000 | .500 | .382 | .882 | 6.4 |
| 12F175 | 88,000 | 80,000 | .500 | .457 | .957 | 15.4 |
| | | | | | Av. .829 | Av. ±12.0 |
| 12F143 | 88,000 | 80,000 | .750 | .325 | 1.075 | 2.9 |
| 12F144 | 88,000 | 80,000 | .750 | .713 | 1.463 | 32.2 |
| 12F145 | 88,000 | 80,000 | .750 | .266 | 1.016 | 8.2 |
| 12F146 | 88,000 | 80,000 | .750 | .123 | .873 | 21.1 |
| | | | | | Av. 1.107 | Av. ±16.1 |

TABLE II.- RESULTS OF TWO-STEP TESTS AT ROOM TEMPERATURE - Concluded

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\frac{n_1}{N_1}$ | $R_2$, $\frac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F178 | 82,000 | 94,000 | 0.250 | 0.587 | 0.837 | 11.0 |
| 12F179 | 82,000 | 94,000 | .250 | .630 | .880 | 6.4 |
| 12F180 | 82,000 | 94,000 | .250 | .594 | .844 | 10.2 |
| 12F181 | 82,000 | 94,000 | .250 | .948 | 1.198 | 27.4 |
| | | | | | Av. .940 | Av. ±13.8 |
| 12F182 | 82,000 | 94,000 | .500 | .540 | 1.040 | 3.4 |
| 12F183 | 82,000 | 94,000 | .500 | .867 | 1.267 | 25.9 |
| 12F184 | 82,000 | 94,000 | .500 | .424 | .924 | 6.2 |
| 12F185 | 82,000 | 94,000 | .500 | .292 | .792 | 21.3 |
| | | | | | Av. 1.006 | Av. ±14.2 |
| 12F187 | 82,000 | 94,000 | .750 | .426 | 1.176 | 8.9 |
| 12F188 | 82,000 | 94,000 | .750 | .368 | 1.118 | 3.5 |
| 12F189 | 82,000 | 94,000 | .750 | .204 | .954 | 11.8 |
| 12F230 | 82,000 | 94,000 | .750 | .320 | 1.070 | .9 |
| | | | | | Av. 1.080 | Av. ±6.3 |
| 12F190 | 94,000 | 82,000 | .250 | .254 | .504 | 22.7 |
| 12F191 | 94,000 | 82,000 | .250 | .291 | .541 | 17.0 |
| 12F192 | 94,000 | 82,000 | .250 | .633 | .883 | 35.4 |
| 12F193 | 94,000 | 82,000 | .250 | .431 | .681 | 4.4 |
| | | | | | Av. .652 | Av. ±19.9 |
| 12F194 | 94,000 | 82,000 | .500 | .039 | .539 | 17.7 |
| 12F195 | 94,000 | 82,000 | .500 | .138 | .638 | 2.6 |
| 12F196 | 94,000 | 82,000 | .500 | .252 | .752 | 14.8 |
| 12F197 | 94,000 | 82,000 | .500 | .192 | .692 | 5.6 |
| | | | | | Av. .655 | Av. ±10.2 |
| 12F198 | 94,000 | 82,000 | .750 | .162 | .912 | 4.8 |
| 12F199 | 94,000 | 82,000 | .750 | .034 | .784 | 10.0 |
| 12F201 | 94,000 | 82,000 | .750 | .010 | .760 | 12.6 |
| 12F231 | 94,000 | 82,000 | .750 | .275 | 1.025 | 17.8 |
| | | | | | Av. .870 | Av. ±11.3 |

TABLE III.- RESULTS OF THREE-STEP TESTS AT ROOM TEMPERATURE

[From mean curve: $N$ at 82,000 psi is 224,000 cycles, $N$ at
88,000 psi is 110,000 cycles, and $N$ at 94,000 psi is
53,500 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | $R_3$, $\dfrac{n_3}{N_3}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|
| 12F232 | 82,000 | 88,000 | 94,000 | 0.300 | 0.300 | 1.125 | 1.725 | 4.9 |
| 12F233 | 82,000 | 88,000 | 94,000 | .300 | .300 | 1.052 | 1.652 | .5 |
| 12F235 | 82,000 | 88,000 | 94,000 | .300 | .300 | .746 | 1.346 | 18.1 |
| 12F236 | 82,000 | 88,000 | 94,000 | .300 | .300 | 1.254 | 1.854 | 12.8 |
| | | | | | | | Av. 1.644 | Av. ±9.1 |
| 12F237 | 94,000 | 88,000 | 82,000 | .300 | .300 | .175 | .775 | 1.5 |
| 12F238 | 94,000 | 88,000 | 82,000 | .300 | .300 | .169 | .769 | 2.3 |
| 12F240 | 94,000 | 88,000 | 82,000 | .300 | .300 | .218 | .818 | 3.9 |
| 12F241 | 94,000 | 88,000 | 82,000 | .300 | .300 | .186 | .786 | .1 |
| | | | | | | | Av. .787 | Av. ±2.0 |

TABLE IV.- RESULTS OF FIVE-STEP TESTS AT ROOM TEMPERATURE

[From mean curve: N at 80,000 psi is 282,000 cycles, N at 82,000 psi is 224,000 cycles, N at 85,000 psi is 158,000 cycles, N at 88,000 psi is 110,000 cycles, N at 91,000 psi is 77,000 cycles, and N at 94,000 psi is 53,500 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $R_1$, $\frac{n_1}{N_1}$ | $R_2$, $\frac{n_2}{N_2}$ | $R_3$, $\frac{n_2}{N_3}$ | $R_4$, $\frac{n_4}{N_4}$ | $R_5$, $\frac{n_2}{N_5}$ | Cumulative cycle ratio, $\sum\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12F242 | 82,000 | 85,000 | 88,000 | 91,000 | 94,000 | 0.200 | 0.200 | 0.200 | 0.200 | 0.232 | 1.032 | 6.8 |
| 12F243 | 82,000 | 85,000 | 88,000 | 91,000 | 94,000 | .200 | .200 | .200 | .200 | .553 | 1.353 | 22.2 |
| 12F244 | 82,000 | 85,000 | 88,000 | 91,000 | 94,000 | .200 | .200 | .200 | .200 | .140 | .940 | 15.1 |
| 12F245 | 82,000 | 85,000 | 88,000 | 91,000 | 94,000 | .200 | .200 | .200 | .200 | .093 | .893 | 19.3 |
| 12F246 | 82,000 | 85,000 | 88,000 | 91,000 | 94,000 | .200 | .200 | .200 | .200 | .516 | 1.316 | 18.9 |
| | | | | | | | | | | | Av. 1.107 | Av.±16.5 |
| 12F247 | 94,000 | 91,000 | 88,000 | 85,000 | 82,000 | .200 | .200 | .200 | .200 | .196 | .996 | 13.8 |
| 12F248 | 94,000 | 91,000 | 88,000 | 85,000 | 82,000 | .200 | .200 | .200 | .200 | .107 | .907 | 3.7 |
| 12F249 | 94,000 | 91,000 | 88,000 | 85,000 | 82,000 | .200 | .200 | .200 | .200 | .183 | .983 | 12.3 |
| 12F250 | 94,000 | 91,000 | 88,000 | 85,000 | 82,000 | .200 | .200 | .200 | .149 | 0 | .749 | 14.4 |
| 12F251 | 94,000 | 91,000 | 88,000 | 85,000 | 82,000 | .200 | .200 | .200 | .138 | 0 | .738 | 15.7 |
| | | | | | | | | | | | Av. .875 | Av.±12.0 |
| 12F252 | 80,000 | 88,000 | 80,000 | 88,000 | 80,000 | .200 | .200 | .200 | .200 | .117 | .917 | 8.4 |
| 12F254 | 80,000 | 88,000 | 80,000 | 88,000 | 80,000 | .200 | .200 | .200 | .128 | 0 | .728 | 13.9 |
| 12F255 | 80,000 | 88,000 | 80,000 | 88,000 | 80,000 | .200 | .200 | .200 | .200 | .113 | .913 | 7.9 |
| 12F256 | 80,000 | 88,000 | 80,000 | 88,000 | 80,000 | .200 | .200 | .200 | .200 | .025 | .825 | 2.5 |
| | | | | | | | | | | | Av. .846 | Av. ±8.2 |

TABLE V.- COMPARISON OF ROOM-TEMPERATURE TEST RESULTS WITH RESULTS COMPUTED BY HENRY'S THEORY (REF. 34)

| $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $\frac{n_1}{N_1}$ | $\frac{n_2}{N_2}$ | $\frac{n_3}{N_3}$ | $\frac{n_4}{N_4}$ | Cumulative cycle ratio | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Test average | Henry's theory |
| Two-step tests | | | | | | | | | | |
| 80,000 | 88,000 | | | | 0.250 | | | | 1.134 | 1.160 |
| 80,000 | 88,000 | | | | .500 | | | | 1.481 | 1.271 |
| 80,000 | 88,000 | | | | .750 | | | | 1.374 | 1.279 |
| 88,000 | 80,000 | | | | .250 | | | | .740 | .718 |
| 88,000 | 80,000 | | | | .500 | | | | .829 | .733 |
| 88,000 | 80,000 | | | | .750 | | | | 1.107 | .840 |
| 82,000 | 94,000 | | | | .250 | | | | .940 | 1.150 |
| 82,000 | 94,000 | | | | .500 | | | | 1.006 | 1.246 |
| 82,000 | 94,000 | | | | .750 | | | | 1.080 | 1.247 |
| 94,000 | 82,000 | | | | .250 | | | | .652 | .750 |
| 94,000 | 82,000 | | | | .500 | | | | .655 | .753 |
| 94,000 | 82,000 | | | | .750 | | | | .870 | .851 |
| Three-step tests | | | | | | | | | | |
| 82,000 | 88,000 | 94,000 | | | 0.300 | 0.300 | | | 1.644 | 1.218 |
| 94,000 | 88,000 | 82,000 | | | .300 | .300 | | | .787 | .785 |
| Five-step tests | | | | | | | | | | |
| 82,000 | 85,000 | 88,000 | 91,000 | 94,000 | 0.200 | 0.200 | 0.200 | 0.200 | 1.107 | 1.207 |
| 94,000 | 91,000 | 88,000 | 85,000 | 82,000 | .200 | .200 | .200 | .200 | .875 | .841 |
| 80,000 | 88,000 | 80,000 | 88,000 | 80,000 | .200 | .200 | .200 | .200 | .846 | .928 |

TABLE VI.- RESULTS OF 400° F TESTS AT ONE STRESS LEVEL

[N obtained from mean S-N curve]

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F114 | 84,000 | 55,500 | 49,000 | 1.133 | 7.5 |
| 12F102 | 84,000 | 52,400 | 49,000 | 1.069 | 1.4 |
| 12F115 | 84,000 | 50,000 | 49,000 | 1.020 | 3.3 |
| 12F103 | 84,000 | 48,700 | 49,000 | .994 | 5.7 |
|  |  |  |  | Av. 1.054 | Av. ±4.5 |
|  |  |  |  |  |  |
| 12F98 | 80,000 | 82,500 | 80,000 | 1.031 | 10.6 |
| 12F99 | 80,000 | 77,200 | 80,000 | .965 | 3.5 |
| 12F116 | 80,000 | 72,200 | 80,000 | .903 | 3.1 |
| 12F100 | 80,000 | 66,400 | 80,000 | .830 | 11.0 |
|  |  |  |  | Av. .932 | Av. ±7.1 |
|  |  |  |  |  |  |
| 12F95 | 78,000 | 116,000 | 102,000 | 1.137 | 14.2 |
| 12F97 | 78,000 | 110,500 | 102,000 | 1.083 | 8.8 |
| 12F96 | 78,000 | 94,500 | 102,000 | .926 | 7.0 |
| 12F94 | 78,000 | 85,200 | 102,000 | .835 | 16.1 |
|  |  |  |  | Av. .995 | Av. ±11.5 |
|  |  |  |  |  |  |
| 12F111 | 76,000 | 159,000 | 133,000 | 1.195 | 19.7 |
| 12F110 | 76,000 | 146,500 | 133,000 | 1.102 | 10.4 |
| 12F113 | 76,000 | 139,100 | 133,000 | 1.046 | 4.8 |
| 12F117 | 76,000 | 110,400 | 133,000 | .830 | 16.8 |
| 12F112 | 76,000 | 108,400 | 133,000 | .815 | 18.2 |
|  |  |  |  | Av. .998 | Av. ±14.0 |
|  |  |  |  |  |  |
| 12F92 | 72,000 | 324,400 | 220,000 | 1.474 | 28.4 |
| 12F93 | 72,000 | 321,200 | 220,000 | 1.460 | 27.1 |
| 12F118 | 72,000 | 234,600 | 220,000 | 1.066 | 7.2 |
| 12F58 | 72,000 | 130,400 | 220,000 | .592 | 48.4 |
|  |  |  |  | Av. 1.148 | Av. ±27.8 |
|  |  |  |  |  |  |
| 12F39 | 70,000 | 388,400 | 280,000 | 1.387 | 32.2 |
| 12F38 | 70,000 | 331,900 | 280,000 | 1.185 | 13.0 |
| 12F43 | 70,000 | 273,100 | 280,000 | .975 | 7.1 |
| 12F42 | 70,000 | 253,500 | 280,000 | .905 | 13.7 |
| 12F41 | 70,000 | 221,800 | 280,000 | .792 | 24.5 |
|  |  |  |  | Av. 1.049 | Av. ±18.1 |

TABLE VI.- RESULTS OF 400° F TESTS AT ONE STRESS LEVEL - Concluded

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F109 | 68,000 | 502,900 | 356,000 | 1.413 | 27.9 |
| 12F48 | 68,000 | 403,200 | 356,000 | 1.133 | 2.5 |
| 12F49 | 68,000 | 343,800 | 356,000 | .966 | 12.6 |
| 12F108 | 68,000 | 323,400 | 356,000 | .908 | 17.8 |
| | | | | Av. 1.105 | Av.±15.2 |
| | | | | | |
| 12F55 | 66,000 | 691,800 | 460,000 | 1.504 | 42.2 |
| 12F54 | 66,000 | 558,500 | 460,000 | 1.214 | 14.9 |
| 12F56 | 66,000 | 422,900 | 460,000 | .919 | 13.1 |
| 12F149 | 66,000 | 271,500 | 460,000 | .590 | 44.2 |
| | | | | Av. 1.057 | Av.±28.6 |
| | | | | | |
| 12F157 | 64,000 | 940,900 | 590,000 | 1.595 | 97.6 |
| 12F156 | 64,000 | 544,600 | 590,000 | .923 | 14.4 |
| 12F150 | 64,000 | 326,200 | 590,000 | .553 | 31.5 |
| 12F155 | 64,000 | 293,800 | 594,000 | .498 | 38.6 |
| 12F152 | 64,000 | 274,500 | 590,000 | .465 | 42.4 |
| | | | | Av. .807 | Av.±44.9 |
| | | | | | |
| 12F160 | 62,000 | 10,106,800 | (a b) | | |
| 12F161 | 62,000 | 8,117,200 | (b) | | |
| 12F158 | 62,000 | 3,949,000 | (b) | | |
| 12F159 | 62,000 | 376,300 | (b) | | |
| | | | | | |
| 12F162 | 60,000 | 11,572,400 | (a c) | | |
| 12F163 | 60,000 | 16,837,700 | (a c) | | |

[a]Specimen did not fail.
[b]Stress corresponds to endurance limit.
[c]Stress below endurance limit.

TABLE VII.- RESULTS OF TWO-STEP TESTS AT $400^\circ$ F BASED ON MEAN S-N CURVE

[From mean curve: N at 68,000 psi is 356,000 cycles, N at 70,000 psi is 280,000 cycles, N at 78,000 psi is 102,000 cycles, and N at 80,000 psi is 80,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F164 | 68,000 | 80,000 | 0.250 | 0.493 | 0.743 | 2.7 |
| 12F165 | 68,000 | 80,000 | .250 | .563 | .813 | 6.4 |
| 12F166 | 68,000 | 80,000 | .250 | .379 | .629 | 17.7 |
| 12F168 | 68,000 | 80,000 | .250 | .621 | .871 | 14.0 |
| | | | | | Av. .764 | Av.±10.2 |
| 12F169 | 68,000 | 80,000 | .500 | .166 | .666 | 6.1 |
| 12F170 | 68,000 | 80,000 | .500 | .069 | .569 | 9.4 |
| 12F171 | 68,000 | 80,000 | .500 | .169 | .669 | 6.5 |
| 12F172 | 68,000 | 80,000 | .500 | .108 | .608 | 3.2 |
| | | | | | Av. .628 | Av. ±6.3 |
| 12F203 | 68,000 | 80,000 | .569 | 0 | .569 | 16.9 |
| 12F204 | 68,000 | 80,000 | .604 | 0 | .604 | 11.8 |
| 12F205 | 68,000 | 80,000 | .750 | .018 | .768 | 12.1 |
| 12F206 | 68,000 | 80,000 | .750 | .049 | .799 | 16.6 |
| | | | | | Av. .685 | Av.±14.4 |
| 12F210 | 80,000 | 68,000 | .250 | .231 | .481 | 4.3 |
| 12F211 | 80,000 | 68,000 | .250 | .154 | .404 | 12.4 |
| 12F212 | 80,000 | 68,000 | .250 | .248 | .498 | 8.0 |
| 12F215 | 80,000 | 68,000 | .250 | .212 | .462 | .2 |
| | | | | | Av. .461 | Av. ±6.2 |
| 12F216 | 80,000 | 68,000 | .500 | .128 | .628 | 4.0 |
| 12F217 | 80,000 | 68,000 | .500 | .093 | .593 | 1.8 |
| 12F219 | 80,000 | 68,000 | .500 | .094 | .594 | 1.7 |
| 12F220 | 80,000 | 68,000 | .500 | .102 | .602 | .3 |
| | | | | | Av. .604 | Av. ±2.0 |
| 12F224 | 80,000 | 68,000 | .648 | 0 | .648 | 9.1 |
| 12F225 | 80,000 | 68,000 | .656 | 0 | .656 | 8.0 |
| 12F226 | 80,000 | 68,000 | .684 | 0 | .684 | 4.1 |
| 12F227 | 80,000 | 68,000 | .750 | .112 | .862 | 20.9 |
| | | | | | Av. .713 | Av.±10.5 |

TABLE VII.- RESULTS OF TWO-STEP TESTS AT $400^\circ$ F BASED ON

MEAN S-N CURVE - Concluded

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F228 | 70,000 | 78,000 | 0.250 | 0.436 | 0.686 | 14.2 |
| 12F229 | 70,000 | 78,000 | .250 | .585 | .835 | 4.4 |
| 12F258 | 70,000 | 78,000 | .250 | .651 | .901 | 12.6 |
| 12F259 | 70,000 | 78,000 | .250 | .528 | .778 | 2.7 |
| | | | | | Av. .800 | Av. ±8.5 |
| 12F261 | 70,000 | 78,000 | .500 | .672 | 1.172 | 11.4 |
| 12F262 | 70,000 | 78,000 | .500 | .547 | 1.047 | .5 |
| 12F264 | 70,000 | 78,000 | .500 | .296 | .796 | 24.3 |
| 12F272 | 70,000 | 78,000 | .500 | .691 | 1.191 | 13.2 |
| | | | | | Av. 1.052 | Av. ±12.4 |
| 12F266 | 70,000 | 78,000 | .750 | .133 | .883 | 18.4 |
| 12F267 | 70,000 | 78,000 | .654 | 0 | .654 | 12.3 |
| 12F268 | 70,000 | 78,000 | .750 | .039 | .789 | 5.8 |
| 12F269 | 70,000 | 78,000 | .659 | 0 | .659 | 11.7 |
| | | | | | Av. .746 | Av. ±12.1 |
| 12F275 | 78,000 | 70,000 | .250 | .271 | .521 | 5.5 |
| 12F276 | 78,000 | 70,000 | .250 | .176 | .426 | 13.8 |
| 12F278 | 78,000 | 70,000 | .250 | .198 | .448 | 9.3 |
| 12F279 | 78,000 | 70,000 | .250 | .332 | .582 | 17.8 |
| | | | | | Av. .494 | Av. ±11.6 |
| 12F280 | 78,000 | 70,000 | .500 | .134 | .634 | 2.3 |
| 12F281 | 78,000 | 70,000 | .500 | .158 | .658 | 1.4 |
| 12F282 | 78,000 | 70,000 | .500 | .118 | .618 | 4.8 |
| 12F284 | 78,000 | 70,000 | .500 | .185 | .685 | 5.5 |
| | | | | | Av. .649 | Av. ±3.5 |
| 12F285 | 78,000 | 70,000 | .750 | .054 | .804 | 4.8 |
| 12F286 | 78,000 | 70,000 | .728 | 0 | .728 | 5.1 |
| 12F288 | 78,000 | 70,000 | .676 | 0 | .676 | 11.9 |
| 12F289 | 78,000 | 70,000 | .750 | .110 | .860 | 12.1 |
| | | | | | Av. .767 | Av. ±8.5 |

TABLE VIII.- RESULTS OF TWO-STEP TESTS AT $400^\circ$ F BASED ON

MINIMUM S-N CURVE

[From minimum curve: N at 68,000 psi is 181,000 cycles, N at 70,000 psi is 154,000 cycles, N at 78,000 psi is 79,000 cycles, and N at 80,000 psi is 67,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\displaystyle\sum \frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F164 | 68,000 | 80,000 | 0.492 | 0.588 | 1.080 | 2.4 |
| 12F165 | 68,000 | 80,000 | .492 | .672 | 1.164 | 5.2 |
| 12F166 | 68,000 | 80,000 | .492 | .452 | .944 | 14.6 |
| 12F168 | 68,000 | 80,000 | .492 | .742 | 1.234 | 11.2 |
| | | | | | Av. 1.106 | Av. ±8.4 |
| 12F169 | 68,000 | 80,000 | .983 | .199 | 1.182 | 4.0 |
| 12F170 | 68,000 | 80,000 | .983 | .082 | 1.065 | 6.2 |
| 12F171 | 68,000 | 80,000 | .983 | .201 | 1.184 | 4.2 |
| 12F172 | 68,000 | 80,000 | .983 | .128 | 1.111 | 2.2 |
| | | | | | Av. 1.136 | Av. ±4.2 |
| 12F203 | 68,000 | 80,000 | 1.119 | 0 | 1.119 | 16.1 |
| 12F204 | 68,000 | 80,000 | 1.189 | 0 | 1.189 | 10.9 |
| 12F205 | 68,000 | 80,000 | 1.475 | .021 | 1.496 | 12.1 |
| 12F206 | 68,000 | 80,000 | 1.475 | .058 | 1.533 | 14.9 |
| | | | | | Av. 1.334 | Av. ±13.5 |
| 12F210 | 80,000 | 68,000 | .299 | .455 | .754 | 5.5 |
| 12F211 | 80,000 | 68,000 | .299 | .304 | .603 | 15.7 |
| 12F212 | 80,000 | 68,000 | .299 | .487 | .786 | 9.9 |
| 12F215 | 80,000 | 68,000 | .299 | .417 | .716 | .1 |
| | | | | | Av. .715 | Av. ±7.8 |
| 12F216 | 80,000 | 68,000 | .597 | .251 | .848 | 5.7 |
| 12F217 | 80,000 | 68,000 | .597 | .183 | .780 | 2.7 |
| 12F219 | 80,000 | 68,000 | .597 | .186 | .783 | 2.4 |
| 12F220 | 80,000 | 68,000 | .597 | .200 | .797 | .6 |
| | | | | | Av. .802 | Av. ±2.9 |
| 12F224 | 80,000 | 68,000 | .773 | 0 | .783 | 10.5 |
| 12F225 | 80,000 | 68,000 | .784 | 0 | .784 | 10.4 |
| 12F226 | 80,000 | 68,000 | .816 | 0 | .816 | 6.7 |
| 12F227 | 80,000 | 68,000 | .896 | .219 | 1.115 | 27.4 |
| | | | | | Av. .875 | Av. ±13.8 |

TABLE VIII.- RESULTS OF TWO-STEP TESTS AT $400^\circ$ F BASED ON

MINIMUM S-N CURVE - Concluded

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F228 | 70,000 | 78,000 | 0.455 | 0.563 | 1.018 | 12.7 |
| 12F229 | 70,000 | 78,000 | .455 | .756 | 1.211 | 3.9 |
| 12F258 | 70,000 | 78,000 | .455 | .841 | 1.296 | 11.1 |
| 12F259 | 70,000 | 78,000 | .455 | .682 | 1.137 | 2.5 |
| | | | | | Av. 1.166 | Av. ±7.6 |
| 12F261 | 70,000 | 78,000 | .909 | .867 | 1.776 | 9.6 |
| 12F262 | 70,000 | 78,000 | .909 | .706 | 1.615 | .4 |
| 12F264 | 70,000 | 78,000 | .909 | .382 | 1.291 | 20.4 |
| 12F272 | 70,000 | 78,000 | .909 | .892 | 1.801 | 11.1 |
| | | | | | Av. 1.621 | Av. ±10.4 |
| 12F266 | 70,000 | 78,000 | 1.364 | .172 | 1.536 | 15.1 |
| 12F267 | 70,000 | 78,000 | 1.190 | 0 | 1.190 | 10.9 |
| 12F268 | 70,000 | 78,000 | 1.364 | .051 | 1.415 | 6.0 |
| 12F269 | 70,000 | 78,000 | 1.197 | 0 | 1.197 | 10.3 |
| | | | | | Av. 1.335 | Av. ±10.6 |
| 12F275 | 78,000 | 70,000 | .323 | .492 | .815 | 6.3 |
| 12F276 | 78,000 | 70,000 | .323 | .319 | .642 | 16.3 |
| 12F278 | 78,000 | 70,000 | .323 | .360 | .683 | 11.0 |
| 12F279 | 78,000 | 70,000 | .323 | .603 | .926 | 20.7 |
| | | | | | Av. .767 | Av. ±13.6 |
| 12F280 | 78,000 | 70,000 | .646 | .243 | .889 | 2.9 |
| 12F281 | 78,000 | 70,000 | .646 | .288 | .934 | 2.0 |
| 12F282 | 78,000 | 70,000 | .646 | .214 | .860 | 6.1 |
| 12F284 | 78,000 | 70,000 | .646 | .336 | .982 | 7.2 |
| | | | | | Av. .916 | Av. ±4.6 |
| 12F285 | 78,000 | 70,000 | .968 | .097 | 1.065 | 5.2 |
| 12F286 | 78,000 | 70,000 | .941 | 0 | .941 | 7.0 |
| 12F288 | 78,000 | 70,000 | .873 | 0 | .873 | 13.7 |
| 12F289 | 78,000 | 70,000 | .968 | .200 | 1.168 | 15.4 |
| | | | | | Av. 1.012 | Av. ±10.3 |

TABLE IX.- RESULTS OF THREE-STEP TESTS AT $400^\circ$ F BASED ON MEAN S-N CURVE

[From mean curve: N at 68,000 psi is 356,000 cycles, N at 74,000 psi is 170,000 cycles, and N at 80,000 psi is 80,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | $R_3$, $\dfrac{n_3}{N_3}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|
| 12F290 | 68,000 | 74,000 | 80,000 | 0.300 | 0.300 | 0.911 | 1.511 | 18.0 |
| 12F291 | 68,000 | 74,000 | 80,000 | .300 | .300 | .649 | 1.249 | 2.5 |
| 12F292 | 68,000 | 74,000 | 80,000 | .300 | .300 | .393 | .993 | 22.5 |
| 12F293 | 68,000 | 74,000 | 80,000 | .300 | .300 | .771 | 1.371 | 7.0 |
|  |  |  |  |  |  |  | Av. 1.281 | Av.±12.5 |
| 12F295 | 80,000 | 74,000 | 68,000 | .300 | .266 | 0 | .566 | 9.1 |
| 12F297 | 80,000 | 74,000 | 68,000 | .300 | .300 | .024 | .624 | .2 |
| 12F298 | 80,000 | 74,000 | 68,000 | .300 | .300 | .036 | .636 | 2.1 |
| 12F299 | 80,000 | 74,000 | 68,000 | .300 | .300 | .064 | .664 | 6.6 |
|  |  |  |  |  |  |  | Av. .623 | Av. ±4.5 |

TABLE X.- RESULTS OF THREE-STEP TESTS AT $400^\circ$ F BASED ON

MINIMUM S-N CURVE

[From minimum curve: N at 68,000 psi is 181,000 cycles,
N at 74,000 psi is 111,000 cycles, and N at 80,000 psi
is 67,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $R_1$, $\frac{n_1}{N_1}$ | $R_2$, $\frac{n_2}{N_2}$ | $R_3$, $\frac{n_3}{N_3}$ | Cumulative cycle ratio, $\sum \frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|
| 12F290 | 68,000 | 74,000 | 80,000 | 0.590 | 0.459 | 1.088 | 2.137 | 14.8 |
| 12F291 | 68,000 | 74,000 | 80,000 | .590 | .459 | .775 | 1.824 | 2.0 |
| 12F292 | 68,000 | 74,000 | 80,000 | .590 | .459 | .469 | 1.518 | 18.5 |
| 12F293 | 68,000 | 74,000 | 80,000 | .590 | .459 | .921 | 1.970 | 5.8 |
| | | | | | | | Av. 1.862 | Av. ±10.3 |
| | | | | | | | | |
| 12F295 | 80,000 | 74,000 | 68,000 | .358 | .407 | 0 | .765 | 11.6 |
| 12F297 | 80,000 | 74,000 | 68,000 | .358 | .459 | .046 | .863 | .2 |
| 12F298 | 80,000 | 74,000 | 68,000 | .358 | .459 | .071 | .888 | 2.7 |
| 12F299 | 80,000 | 74,000 | 68,000 | .358 | .459 | .126 | .943 | 9.0 |
| | | | | | | | Av. .865 | Av. ±5.9 |

TABLE XI.- RESULTS OF FIVE-STEP TESTS AT 400° F BASED ON MEAN S-N CURVE

[From mean curve:  N at 68,000 psi is 356,000 cycles,  N at 70,000 psi is 280,000 cyles,  N at 72,000 psi is 220,000 cycles,  N at 74,000 psi is 170,000 cycles, and N at 76,000 psi is 133,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | $R_3$, $\dfrac{n_3}{N_3}$ | $R_4$, $\dfrac{n_4}{N_4}$ | $R_5$, $\dfrac{n_5}{N_5}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12F300 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | 0.200 | 0.200 | 0.200 | 0.200 | 0.559 | 1.359 | 11.7 |
| 12F301 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | .200 | .200 | .200 | .200 | .738 | 1.538 | .6 |
| 12F302 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | .200 | .200 | .200 | .200 | 1.244 | 2.044 | 32.8 |
| 12F304 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | .200 | .200 | .200 | .200 | .414 | 1.214 | 21.1 |
|  |  |  |  |  |  |  |  |  |  |  | Av. 1.539 | Av. ±16.6 |
| 12F305 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .200 | .200 | .172 | 0 | 0 | .572 | 19.3 |
| 12F307 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .200 | .200 | .200 | .165 | 0 | .765 | 7.9 |
| 12F308 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .200 | .200 | .200 | .177 | 0 | .777 | 9.6 |
| 12F309 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .200 | .200 | .200 | .123 | 0 | .723 | 2.0 |
|  |  |  |  |  |  |  |  |  |  |  | Av. .709 | Av. ±9.7 |
| 12F310 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .200 | .200 | .200 | .162 | 0 | .762 | 17.4 |
| 12F311 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .200 | .200 | .078 | 0 | 0 | .478 | 26.3 |
| 12F312 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .200 | .200 | .200 | .001 | 0 | .601 | 7.4 |
| 12F313 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .200 | .200 | .200 | .153 | 0 | .752 | 16.0 |
|  |  |  |  |  |  |  |  |  |  |  | Av. .649 | Av. ±16.8 |

TABLE XII.- RESULTS OF FIVE-STEP TESTS AT 400° F BASED ON MINIMUM S-N CURVE

[From minimum curve: N at 68,000 psi is 181,000 cycles, N at 70,000 psi is 154,000 cycles, N at 72,000 psi is 131,000 cycles, N at 74,000 psi is 111,000 cycles, and N at 76,000 psi is 93,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $R_1$, $\frac{n_1}{N_1}$ | $R_2$, $\frac{n_2}{N_2}$ | $R_3$, $\frac{n_3}{N_3}$ | $R_4$, $\frac{n_4}{N_4}$ | $R_5$, $\frac{n_5}{N_5}$ | Cumulative cycle ratio, $\sum \frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12F300 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | 0.393 | 0.364 | 0.336 | 0.306 | 0.800 | 2.199 | 10.5 |
| 12F301 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | .393 | .364 | .336 | .306 | 1.056 | 2.455 | 0 |
| 12F302 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | .393 | .364 | .336 | .306 | 1.780 | 3.179 | 29.4 |
| 12F304 | 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | .393 | .364 | .336 | .306 | .592 | 1.991 | 18.9 |
| | | | | | | | | | | Av. | 2.456 | Av. ±14.7 |
| 12F305 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .286 | .306 | .289 | 0 | 0 | .881 | 21.8 |
| 12F307 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .286 | .306 | .336 | .299 | 0 | 1.227 | 8.9 |
| 12F308 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .286 | .306 | .336 | .322 | 0 | 1.250 | 10.9 |
| 12F309 | 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .286 | .306 | .336 | .223 | 0 | 1.151 | 2.1 |
| | | | | | | | | | | Av. | 1.127 | Av. ±10.9 |
| 12F310 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .393 | .286 | .393 | .231 | 0 | 1.303 | 15.5 |
| 12F311 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .393 | .286 | .153 | 0 | 0 | .832 | 26.2 |
| 12F312 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .393 | .286 | .393 | .014 | 0 | 1.086 | 3.7 |
| 12F313 | 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .393 | .286 | .393 | .219 | 0 | 1.291 | 14.5 |
| | | | | | | | | | | Av. | 1.128 | Av. ±15.0 |

TABLE XIII.- COMPARISON OF 400° F TEST RESULTS WITH RESULTS COMPUTED BY HENRY'S THEORY (REF. 34)

| $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $\frac{n_1}{N_1}$ | $\frac{n_2}{N_2}$ | $\frac{n_3}{N_3}$ | $\frac{n_4}{N_4}$ | Cumulative cycle ratio Test average (a) | Cumulative cycle ratio Henry's theory |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Two-step tests | | | | | |
| 68,000 | 80,000 | | | | 0.492 | | | | 1.106 | 1.216 |
| 68,000 | 80,000 | | | | .983 | | | | 1.136 | 1.025 |
| 68,000 | 80,000 | | | | 1.475 | | | | 1.334 | (b) |
| 80,000 | 68,000 | | | | .299 | | | | .715 | .775 |
| 80,000 | 68,000 | | | | .597 | | | | .802 | .807 |
| 80,000 | 68,000 | | | | .896 | | | | .875 | .940 |
| 70,000 | 78,000 | | | | .455 | | | | 1.166 | 1.139 |
| 70,000 | 78,000 | | | | .909 | | | | 1.621 | 1.061 |
| 70,000 | 78,000 | | | | 1.364 | | | | 1.335 | (b) |
| 78,000 | 70,000 | | | | .323 | | | | .767 | .864 |
| 78,000 | 70,000 | | | | .646 | | | | .916 | .880 |
| 78,000 | 70,000 | | | | .968 | | | | 1.012 | .986 |
| | | | | | Three-step tests | | | | | |
| 68,000 | 74,000 | 80,000 | | | 0.590 | 0.459 | | | 1.862 | 1.184 |
| 80,000 | 74,000 | 68,000 | | | .358 | .459 | | | .865 | .877 |
| | | | | | Five-step tests | | | | | |
| 68,000 | 70,000 | 72,000 | 74,000 | 76,000 | 0.393 | 0.364 | 0.336 | 0.306 | 2.456 | 1.105 |
| 76,000 | 74,000 | 72,000 | 70,000 | 68,000 | .286 | .306 | .336 | .364 | 1.127 | .937 |
| 68,000 | 76,000 | 68,000 | 76,000 | 68,000 | .393 | .286 | .393 | .286 | 1.128 | .986 |

aFrom results based on minimum S-N curve.
bTheoretical analysis not applicable since cycle ratio at initial stress exceeds unity.

TABLE XIV.- RESULTS OF 800° F TESTS AT ONE STRESS LEVEL

[N obtained from mean S-N curve]

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F342 | 82,000 | 41,100 | 40,000 | 1.028 | 18.5 |
| 12F363 | 82,000 | 49,400 | 40,000 | 1.235 | 2.9 |
| 12F344 | 82,000 | 53,100 | 40,000 | 1.328 | 5.2 |
| 12F345 | 82,000 | 58,200 | 40,000 | 1.455 | 15.3 |
| | | | | Av. 1.262 | Av. ±10.5 |
| | | | | | |
| 12F347 | 80,000 | 40,900 | 65,000 | .629 | 33.4 |
| 12F346 | 80,000 | 43,200 | 65,000 | .665 | 29.6 |
| 12F365 | 80,000 | 45,200 | 65,000 | .695 | 26.4 |
| 12F364 | 80,000 | 47,200 | 65,000 | .726 | 23.1 |
| 12F325 | 80,000 | 62,800 | 65,000 | .966 | 2.3 |
| 12F330 | 80,000 | 79,800 | 65,000 | 1.228 | 30.0 |
| 12F327 | 80,000 | 110,200 | 65,000 | 1.700 | 80.0 |
| | | | | Av. .944 | Av. ±32.1 |
| | | | | | |
| 12F348 | 78,000 | 65,800 | 110,000 | .598 | 42.1 |
| 12F431 | 78,000 | 75,000 | 110,000 | .682 | 34.0 |
| 12F435 | 78,000 | 102,100 | 110,000 | .928 | 10.2 |
| 12F323 | 78,000 | 103,600 | 110,000 | .942 | 8.8 |
| 12F432 | 78,000 | 111,200 | 110,000 | 1.011 | 2.1 |
| 12F334 | 78,000 | 127,700 | 110,000 | 1.161 | 12.3 |
| 12F434 | 78,000 | 131,800 | 110,000 | 1.198 | 16.0 |
| 12F335 | 78,000 | 192,200 | 110,000 | 1.747 | 69.1 |
| | | | | Av. 1.033 | Av. ±24.3 |
| | | | | | |
| 12F350 | 76,000 | 93,800 | 184,000 | .510 | 50.6 |
| 12F372 | 76,000 | 132,600 | 184,000 | .721 | 30.0 |
| 12F371 | 76,000 | 222,800 | 184,000 | 1.211 | 17.2 |
| 12F322 | 76,000 | 226,900 | 184,000 | 1.233 | 19.4 |
| 12F352 | 76,000 | 274,600 | 184,000 | 1.492 | 44.4 |
| | | | | Av. 1.033 | Av. ±32.3 |
| | | | | | |
| 12F353 | 74,000 | 360,800 | 308,000 | 1.171 | 8.4 |
| 12F354 | 74,000 | 377,800 | 308,000 | 1.227 | 4.0 |
| 12F355 | 74,000 | 417,300 | 308,000 | 1.355 | 6.0 |
| 12F321 | 74,000 | 418,100 | 308,000 | 1.357 | 6.2 |
| | | | | Av. 1.278 | Av. ±6.2 |

TABLE XIV.- RESULTS OF 800° F TESTS AT ONE STRESS LEVEL - Continued

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F367 | 72,000 | 181,100 | 518,000 | 0.350 | 71.1 |
| 12F433 | 72,000 | 235,000 | 518,000 | .454 | 62.5 |
| 12F320 | 72,000 | 493,000 | 518,000 | .952 | 21.4 |
| 12F368 | 72,000 | 571,400 | 518,000 | 1.103 | 8.9 |
| 12F436 | 72,000 | 732,800 | 518,000 | 1.415 | 16.8 |
| 12F369 | 72,000 | 867,100 | 518,000 | 1.674 | 38.2 |
| 12F366 | 72,000 | 1,118,500 | 518,000 | 2.159 | 78.3 |
|  |  |  |  | Av. 1.211 | Av. ±42.4 |
| 12F356 | 70,000 | 759,300 | 860,000 | .883 | 33.3 |
| 12F438 | 70,000 | 803,500 | 860,000 | .934 | 29.4 |
| 12F340 | 70,000 | 1,043,000 | 860,000 | 1.212 | 8.4 |
| 12F437 | 70,000 | 1,141,700 | 860,000 | 1.327 | .3 |
| 12F440 | 70,000 | 1,193,800 | 860,000 | 1.388 | 4.9 |
| 12F341 | 70,000 | 1,223,000 | 860,000 | 1.422 | 7.5 |
| 12F319 | 70,000 | 1,328,300 | 860,000 | 1.544 | 16.7 |
| 12F339 | 70,000 | 1,617,500 | 860,000 | 1.880 | 42.1 |
|  |  |  |  | Av. 1.323 | Av. ±17.8 |
| 12F381 | 68,000 | 518,100 | 1,500,000 | .345 | 60.1 |
| 12F384 | 68,000 | 654,300 | 1,500,000 | .436 | 49.5 |
| 12F383 | 68,000 | 742,100 | 1,500,000 | .495 | 42.6 |
| 12F382 | 68,000 | 820,300 | 1,500,000 | .547 | 36.6 |
| 12F358 | 68,000 | 1,113,300 | 1,500,000 | .742 | 14.1 |
| 12F357 | 68,000 | 1,671,000 | 1,500,000 | 1.114 | 29.0 |
| 12F318 | 68,000 | 2,293,300 | 1,500,000 | 1.529 | 77.1 |
| 12F337 | 68,000 | 2,545,800 | 1,500,000 | 1.697 | 96.6 |
|  |  |  |  | Av. .863 | Av. ±50.7 |
| 12F317 | 66,000 | 3,374,800 | 3,120,000 | 1.082 | 19.9 |
| 12F332 | 66,000 | 3,994,000 | 3,120,000 | 1.280 | 5.2 |
| 12F326 | 66,000 | 4,303,700 | 3,120,000 | 1.379 | 2.1 |
| 12F328 | 66,000 | 5,178,500 | 3,120,000 | 1.660 | 30.0 |
|  |  |  |  | Av. 1.350 | Av. ±14.3 |

TABLE XIV.- RESULTS OF $800^\circ$ F TESTS AT ONE STRESS LEVEL - Concluded

| Specimen number | Stress, psi | Cycles to failure, n | Mean life, N | Cycle ratio, $\frac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|
| 12F362 | 65,000 | 2,807,600 | 5,150,000 | 0.545 | 58.4 |
| 12F360 | 65,000 | 4,287,700 | 5,150,000 | .833 | 36.4 |
| 12F359 | 65,000 | 4,748,700 | 5,150,000 | .922 | 29.6 |
| 12F370 | 65,000 | 8,677,600 | 5,150,000 | 1.685 | 28.6 |
| 12F361 | 65,000 | 13,223,500 | 5,150,000 | 2.567 | 96.0 |
| | | | | Av. 1.310 | Av. ±49.8 |

TABLE XV.- RESULTS OF TWO-STEP TESTS AT $800^{\circ}$ F

[From mean curve:  N  at 74,000 psi is 308,000 cycles and
N  at 78,000 psi is 110,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|
| 12F478 | 74,000 | 78,000 | 0.250 | 0.709 | 0.959 | 21.3 |
| 12F446 | 74,000 | 78,000 | .250 | .837 | 1.087 | 10.8 |
| 12F442 | 74,000 | 78,000 | .250 | .865 | 1.115 | 8.5 |
| 12F473 | 74,000 | 78,000 | .250 | 1.211 | 1.461 | 19.9 |
| 12F444 | 74,000 | 78,000 | .250 | 1.225 | 1.475 | 21.0 |
|  |  |  |  |  | Av. 1.219 | Av. ±16.3 |
| 12F451 | 74,000 | 78,000 | .500 | .426 | .926 | 21.1 |
| 12F482 | 74,000 | 78,000 | .500 | .468 | .968 | 17.5 |
| 12F477 | 74,000 | 78,000 | .500 | .567 | 1.067 | 9.1 |
| 12F447 | 74,000 | 78,000 | .500 | .930 | 1.430 | 21.8 |
| 12F483 | 74,000 | 78,000 | .500 | .981 | 1.481 | 26.1 |
|  |  |  |  |  | Av. 1.174 | Av. ±19.1 |
| 12F454 | 74,000 | 78,000 | .581 | 0 | .581 | 43.4 |
| 12F481 | 74,000 | 78,000 | .750 | .250 | 1.000 | 2.6 |
| 12F452 | 74,000 | 78,000 | .750 | .327 | 1.077 | 4.9 |
| 12F456 | 74,000 | 78,000 | .750 | .699 | 1.449 | 41.1 |
|  |  |  |  |  | Av. 1.027 | Av. ±23.0 |
| 12F460 | 78,000 | 74,000 | .250 | .141 | .391 | 22.9 |
| 12F459 | 78,000 | 74,000 | .250 | .224 | .474 | 6.5 |
| 12F457 | 78,000 | 74,000 | .250 | .273 | .523 | 3.2 |
| 12F461 | 78,000 | 74,000 | .250 | .390 | .640 | 26.2 |
|  |  |  |  |  | Av. .507 | Av. ±14.7 |
| 12F467 | 78,000 | 74,000 | .500 | .006 | .506 | 18.4 |
| 12F463 | 78,000 | 74,000 | .500 | .069 | .569 | 8.2 |
| 12F466 | 78,000 | 74,000 | .500 | .100 | .600 | 3.2 |
| 12F465 | 78,000 | 74,000 | .500 | .305 | .805 | 29.8 |
|  |  |  |  |  | Av. .620 | Av. ±14.9 |
| 12F470 | 78,000 | 74,000 | .623 | 0 | .623 | 12.1 |
| 12F472 | 78,000 | 74,000 | .626 | 0 | .626 | 11.7 |
| 12F469 | 78,000 | 74,000 | .719 | 0 | .719 | 1.4 |
| 12F485 | 78,000 | 74,000 | .750 | .027 | .777 | 9.6 |
| 12F468 | 78,000 | 74,000 | .750 | .049 | .799 | 12.7 |
|  |  |  |  |  | Av. .709 | Av. ±11.9 |

TABLE XV.- RESULTS OF TWO-STEP TESTS AT $800^\circ$ F - Concluded

| Specimen number | $S_1$, psi | $S_2$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviative from average, percent |
|---|---|---|---|---|---|---|
| 12F491 | 80,000 | 72,000 | 0.250 | 0.085 | 0.335 | 41.8 |
| 12F487 | 80,000 | 72,000 | .250 | .309 | .559 | 2.9 |
| 12F488 | 80,000 | 72,000 | .250 | .343 | .593 | 3.0 |
| 12F492 | 80,000 | 72,000 | .250 | .566 | .816 | 41.7 |
|  |  |  |  |  | Av. .576 | Av. ±22.4 |
| 12F496 | 80,000 | 72,000 | .454 | 0 | .454 | 10.8 |
| 12F494 | 80,000 | 72,000 | .500 | .001 | .501 | 1.6 |
| 12F497 | 80,000 | 72,000 | .500 | .029 | .529 | 3.9 |
| 12F495 | 80,000 | 72,000 | .500 | .053 | .553 | 8.6 |
|  |  |  |  |  | Av. .509 | Av. ±6.2 |
| 12F502 | 80,000 | 72,000 | .514 | 0 | .514 | 20.1 |
| 12F498 | 80,000 | 72,000 | .586 | 0 | .586 | 8.9 |
| 12F503 | 80,000 | 72,000 | .628 | 0 | .628 | 2.3 |
| 12F500 | 80,000 | 72,000 | .692 | 0 | .692 | 7.6 |
| 12F499 | 80,000 | 72,000 | .750 | .044 | .794 | 23.5 |
|  |  |  |  |  | Av. .643 | Av. ±12.5 |
| 12F507 | 72,000 | 80,000 | .250 | .597 | .847 | 24.3 |
| 12F506 | 72,000 | 80,000 | .250 | .905 | 1.155 | 3.2 |
| 12F508 | 72,000 | 80,000 | .250 | .958 | 1.208 | 8.0 |
| 12F504 | 72,000 | 80,000 | .250 | 1.015 | 1.265 | 13.0 |
|  |  |  |  |  | Av. 1.119 | Av. ±12.1 |
| 12F510 | 72,000 | 80,000 | .500 | .614 | 1.114 | 27.1 |
| 12F509 | 72,000 | 80,000 | .500 | .646 | 1.146 | 25.0 |
| 12F511 | 72,000 | 80,000 | .500 | 1.209 | 1.709 | 11.8 |
| 12F512 | 72,000 | 80,000 | .500 | 1.306 | 1.806 | 18.1 |
| 12F513 | 72,000 | 80,000 | .500 | 1.371 | 1.871 | 22.4 |
|  |  |  |  |  | Av. 1.529 | Av. ±20.9 |
| 12F514 | 72,000 | 80,000 | .750 | .662 | 1.412 | 19.1 |
| 12F517 | 72,000 | 80,000 | .750 | .942 | 1.692 | 3.0 |
| 12F515 | 72,000 | 80,000 | .750 | 1.049 | 1.799 | 3.1 |
| 12F516 | 72,000 | 80,000 | .750 | 1.326 | 2.076 | 19.0 |
|  |  |  |  |  | Av. 1.745 | Av. ±11.1 |

TABLE XVI.- RESULTS OF THREE-STEP TESTS AT 800° F

[From mean curve: N at 72,000 psi is 518,000 cycles, N at 76,000 psi
is 184,000 cycles, and N at 80,000 psi is 65,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | $R_3$, $\dfrac{n_3}{N_3}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|
| 12F522 | 72,000 | 76,000 | 80,000 | 0.300 | 0.209 | 0 | 0.509 | 12.8 |
| 12F528 | 72,000 | 76,000 | 80,000 | .300 | .257 | 0 | .557 | 4.6 |
| 12F530 | 72,000 | 76,000 | 80,000 | .300 | .271 | 0 | .571 | 2.2 |
| 12F526 | 72,000 | 76,000 | 80,000 | .300 | .300 | .011 | .611 | 4.6 |
| 12F525 | 72,000 | 76,000 | 80,000 | .300 | .300 | .074 | .674 | 15.4 |
| | | | | | | | Av. .584 | Av. ±7.9 |
| | | | | | | | | |
| 12F532 | 80,000 | 76,000 | 72,000 | .300 | .078 | 0 | .378 | 16.0 |
| 12F533 | 80,000 | 76,000 | 72,000 | .300 | .091 | 0 | .391 | 13.1 |
| 12F531 | 80,000 | 76,000 | 72,000 | .300 | .110 | 0 | .410 | 8.9 |
| 12F537 | 80,000 | 76,000 | 72,000 | .300 | .179 | 0 | .479 | 6.4 |
| 12F535 | 80,000 | 76,000 | 72,000 | .300 | .208 | 0 | .508 | 12.9 |
| 12F534 | 80,000 | 76,000 | 72,000 | .300 | .234 | 0 | .534 | 18.7 |
| | | | | | | | Av. .450 | Av. ±12.7 |

TABLE XVII.- RESULTS OF FIVE-STEP TESTS AT 800° F

[From mean curve: N at 72,000 psi is 518,000 cycles, N at 74,000 psi is 308,000 cycles, N at 76,000 psi is 184,000 cycles, N at 78,000 cycles is 110,000 cycles, and N at 80,000 psi is 65,000 cycles]

| Specimen number | $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $R_1$, $\dfrac{n_1}{N_1}$ | $R_2$, $\dfrac{n_2}{N_2}$ | $R_3$, $\dfrac{n_3}{N_3}$ | $R_4$, $\dfrac{n_4}{N_4}$ | $R_5$, $\dfrac{n_5}{N_5}$ | Cumulative cycle ratio, $\sum \dfrac{n}{N}$ | Deviation from average, percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12F539 | 72,000 | 74,000 | 76,000 | 78,000 | 80,000 | 0.200 | 0.200 | 0.184 | 0 | 0 | 0.584 | 33.9 |
| 12F543 | 72,000 | 74,000 | 76,000 | 78,000 | 80,000 | .200 | .200 | .200 | .172 | 0 | .772 | 12.7 |
| 12F538 | 72,000 | 74,000 | 76,000 | 78,000 | 80,000 | .200 | .200 | .200 | .200 | .109 | .909 | 2.8 |
| 12F540 | 72,000 | 74,000 | 76,000 | 78,000 | 80,000 | .200 | .200 | .200 | .200 | .471 | 1.271 | 43.7 |
|  |  |  |  |  |  |  |  |  |  | Av. | .884 | Av. ±23.3 |
| 12F548 | 80,000 | 78,000 | 76,000 | 74,000 | 72,000 | .200 | .200 | .013 | 0 | 0 | .413 | 10.0 |
| 12F546 | 80,000 | 78,000 | 76,000 | 74,000 | 72,000 | .200 | .200 | .036 | 0 | 0 | .436 | 5.0 |
| 12F549 | 80,000 | 78,000 | 76,000 | 74,000 | 72,000 | .200 | .200 | .043 | 0 | 0 | .443 | 3.5 |
| 12F547 | 80,000 | 78,000 | 76,000 | 74,000 | 72,000 | .200 | .200 | .152 | 0 | 0 | .542 | 18.1 |
|  |  |  |  |  |  |  |  |  |  | Av. | .459 | Av. ±9.2 |
| 12F556 | 72,000 | 80,000 | 72,000 | 80,000 | 72,000 | .200 | .069 | 0 | 0 | 0 | .269 | 29.0 |
| 12F552 | 72,000 | 80,000 | 72,000 | 80,000 | 72,000 | .200 | .192 | 0 | 0 | 0 | .392 | 3.4 |
| 12F550 | 72,000 | 80,000 | 72,000 | 80,000 | 72,000 | .200 | .200 | .033 | 0 | 0 | .433 | 14.2 |
| 12F554 | 72,000 | 80,000 | 72,000 | 80,000 | 72,000 | .200 | .200 | .022 | 0 | 0 | .422 | 11.3 |
|  |  |  |  |  |  |  |  |  |  | Av. | .379 | Av. ±14.5 |

TABLE XVIII.- COMPARISON OF 800° F TEST RESULTS WITH RESULTS COMPUTED BY HENRY'S THEORY (REF. 34)

| $S_1$, psi | $S_2$, psi | $S_3$, psi | $S_4$, psi | $S_5$, psi | $\frac{n_1}{N_1}$ | $\frac{n_2}{N_2}$ | $\frac{n_3}{N_3}$ | $\frac{n_4}{N_5}$ | Cumulative cycle ratio | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Test average | Henry's theory |
| Two-step tests | | | | | | | | | | |
| 72,000 | 80,000 | | | | 0.250 | | | | 1.119 | 1.097 |
| 72,000 | 80,000 | | | | .500 | | | | 1.529 | 1.147 |
| 72,000 | 80,000 | | | | .750 | | | | 1.745 | 1.129 |
| 80,000 | 72,000 | | | | .250 | | | | .576 | .867 |
| 80,000 | 72,000 | | | | .500 | | | | .509 | .853 |
| 80,000 | 72,000 | | | | .750 | | | | .643 | .904 |
| 74,000 | 78,000 | | | | .250 | | | | 1.219 | 1.052 |
| 74,000 | 78,000 | | | | .500 | | | | 1.174 | 1.072 |
| 74,000 | 78,000 | | | | .750 | | | | 1.027 | 1.058 |
| 78,000 | 74,000 | | | | .250 | | | | .507 | .939 |
| 78,000 | 74,000 | | | | .500 | | | | .620 | .929 |
| 78,000 | 74,000 | | | | .750 | | | | .709 | .950 |
| Three-step tests | | | | | | | | | | |
| 72,000 | 76,000 | 80,000 | | | 0.300 | 0.300 | | | 0.584 | 1.133 |
| 80,000 | 76,000 | 72,000 | | | .300 | .300 | | | .450 | .872 |
| Five-step tests | | | | | | | | | | |
| 72,000 | 74,000 | 76,000 | 78,000 | 80,000 | 0.200 | 0.200 | 0.200 | 0.200 | 0.884 | 1.090 |
| 80,000 | 78,000 | 76,000 | 74,000 | 72,000 | .200 | .200 | .200 | .200 | .459 | .866 |
| 72,000 | 80,000 | 72,000 | 80,000 | 72,000 | .200 | .200 | .200 | .200 | .379 | .979 |
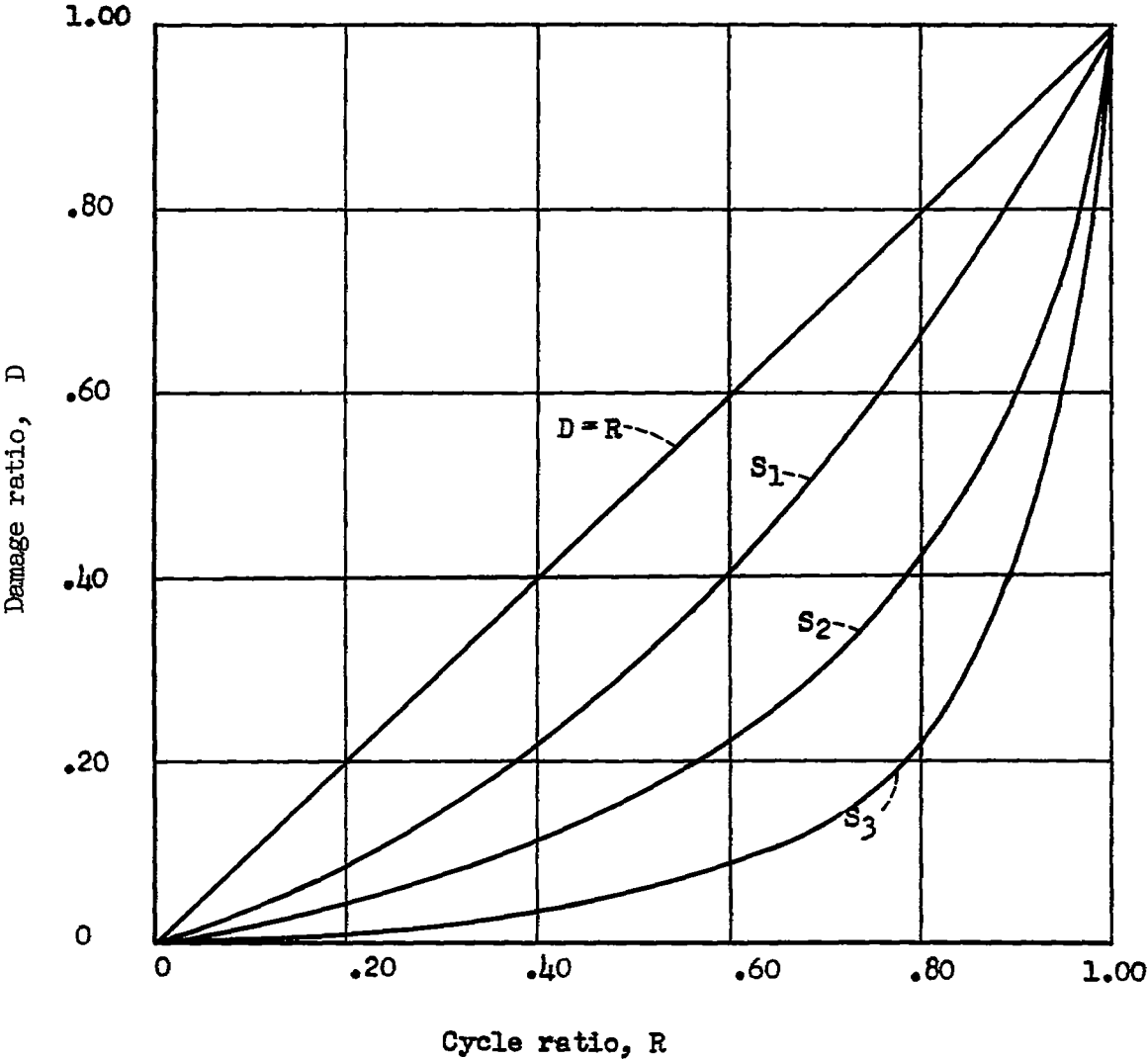
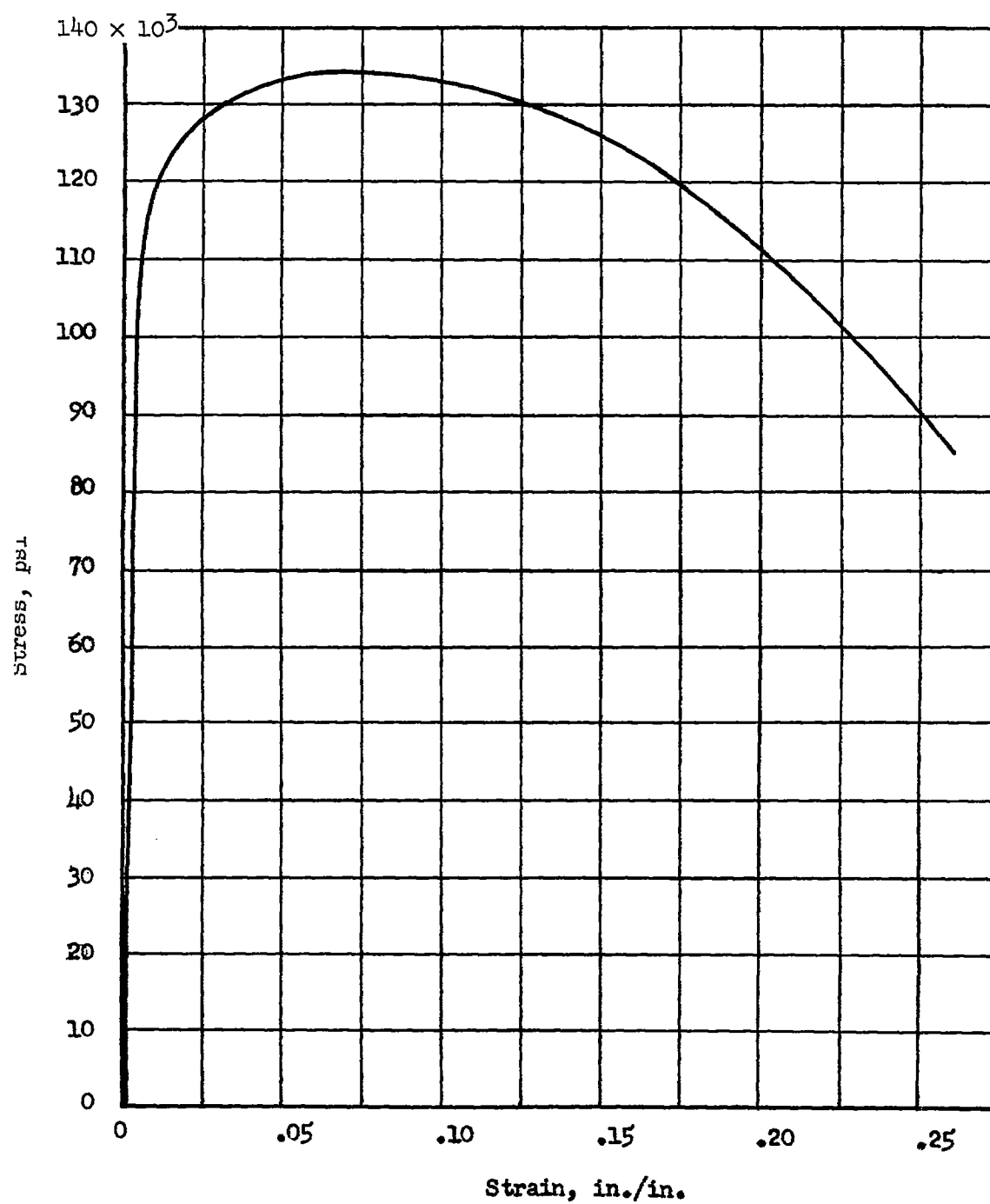Figure 1.- Typical curves of damage ratio plotted against cycle ratio.

Figure 2.- Average tensile stress-strain curve for SAE 4130 stainless
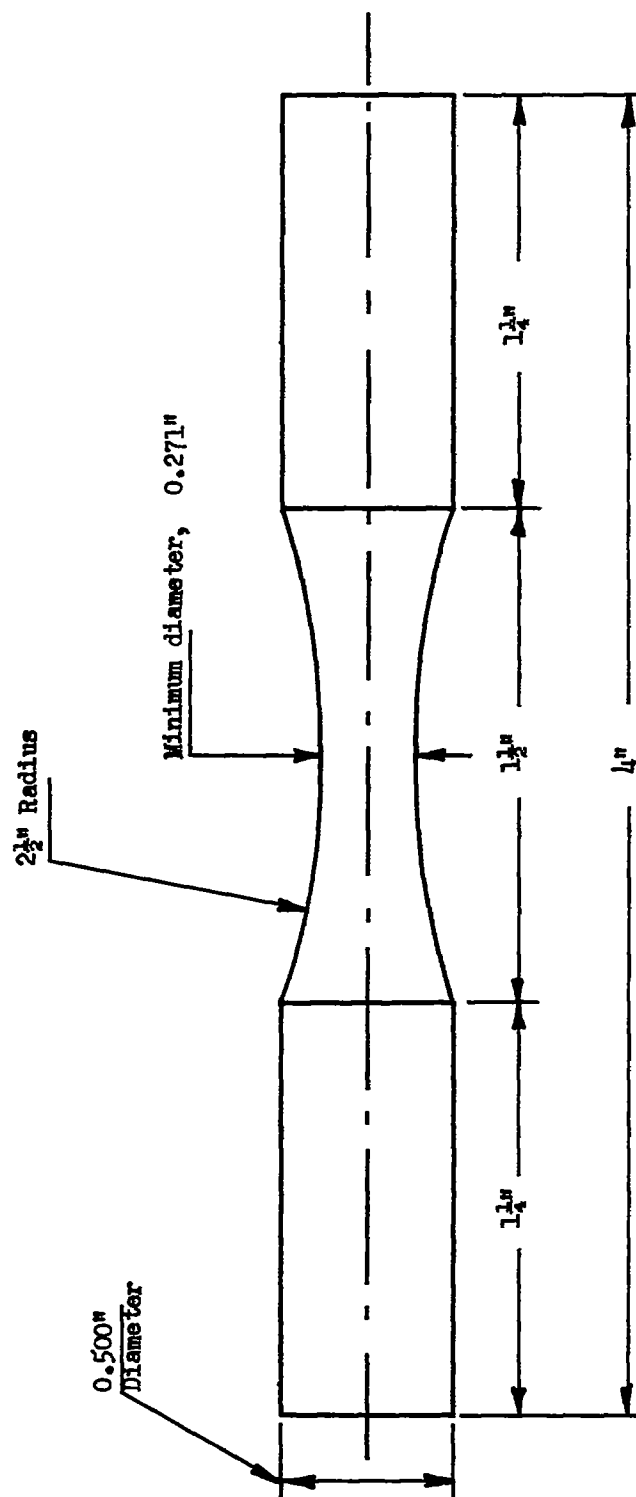steel at room temperature.

Figure 3.- Dimensions of $\frac{1}{2}$- inch-diameter rotating-beam fatigue specimen.
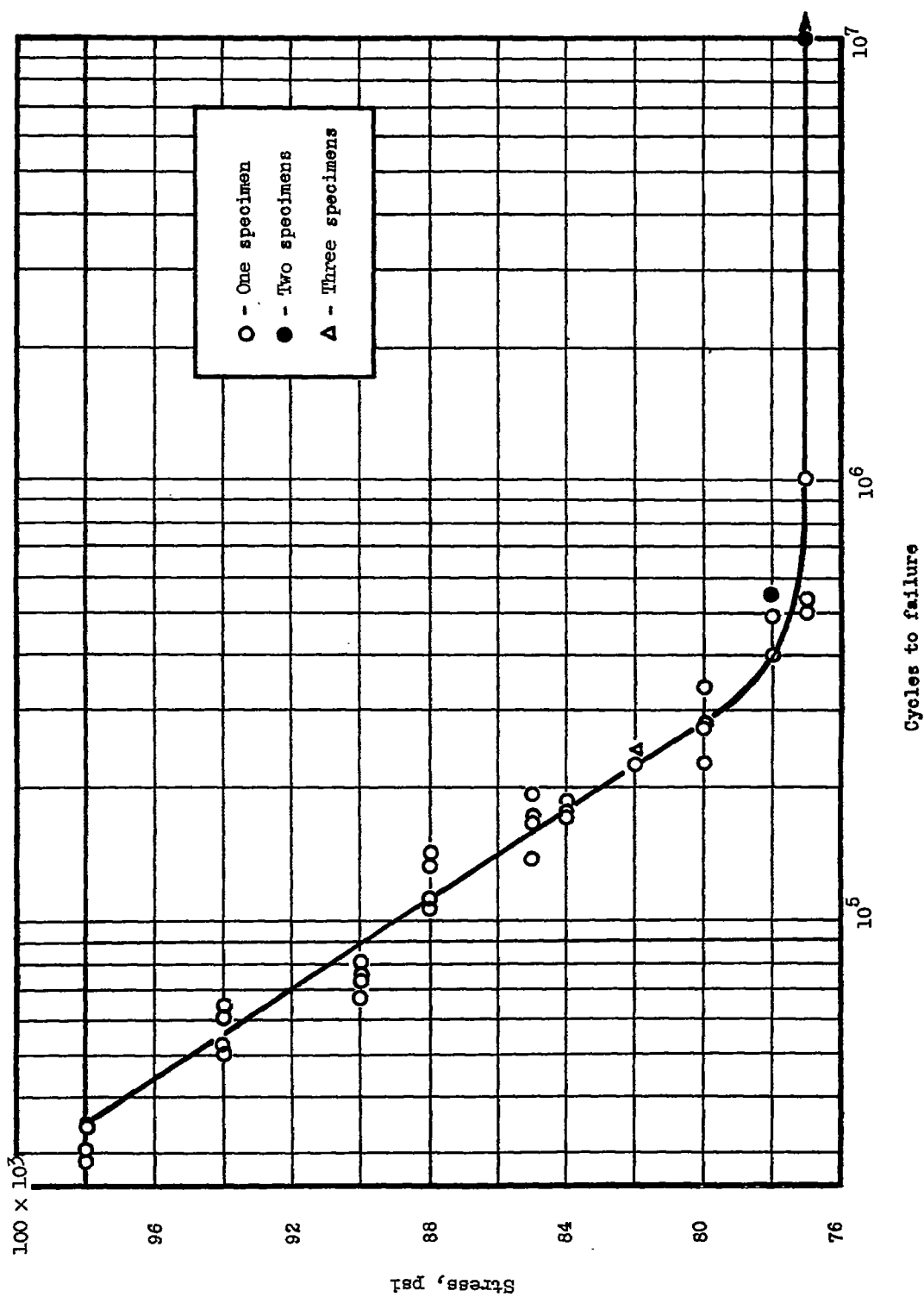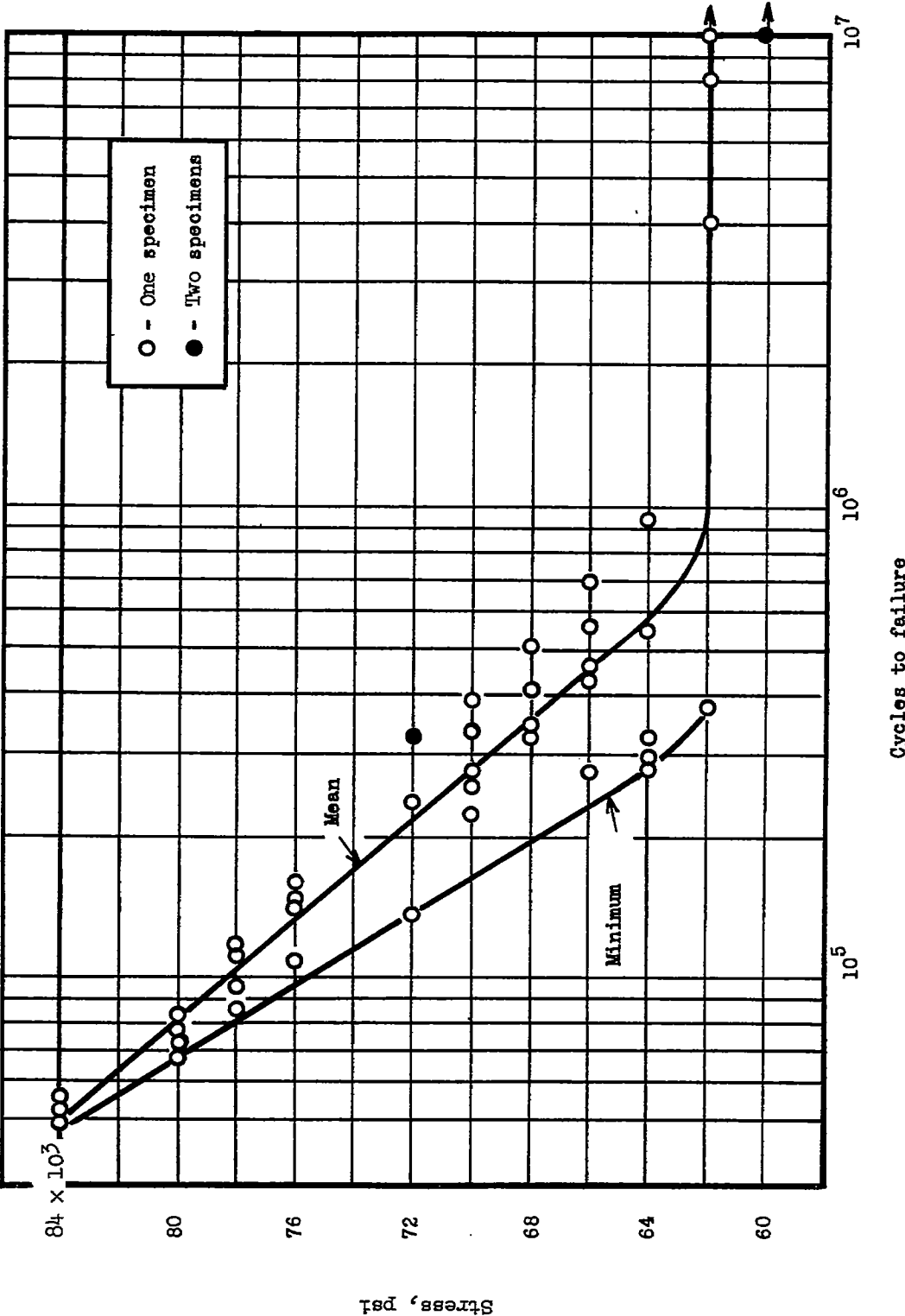
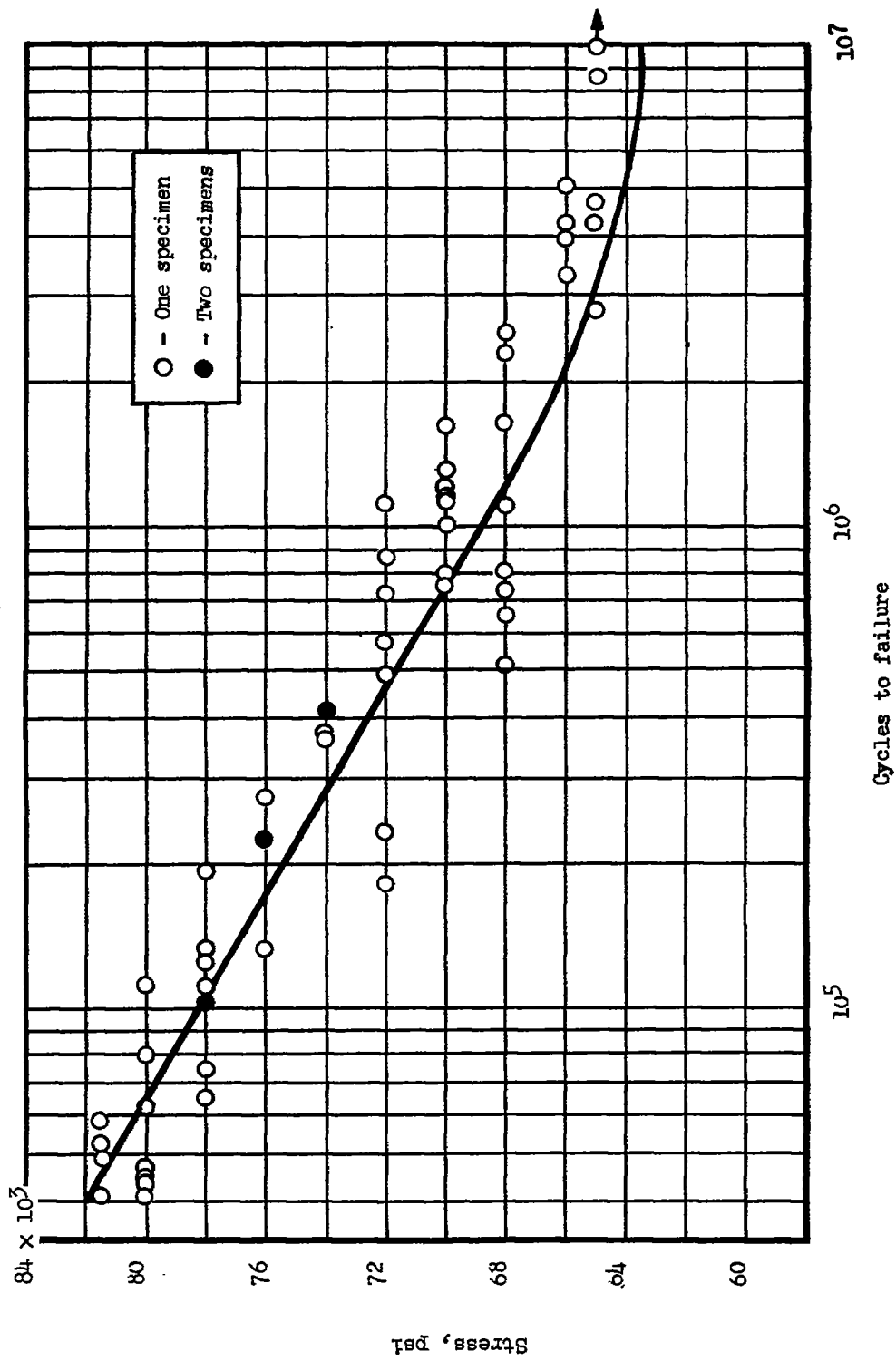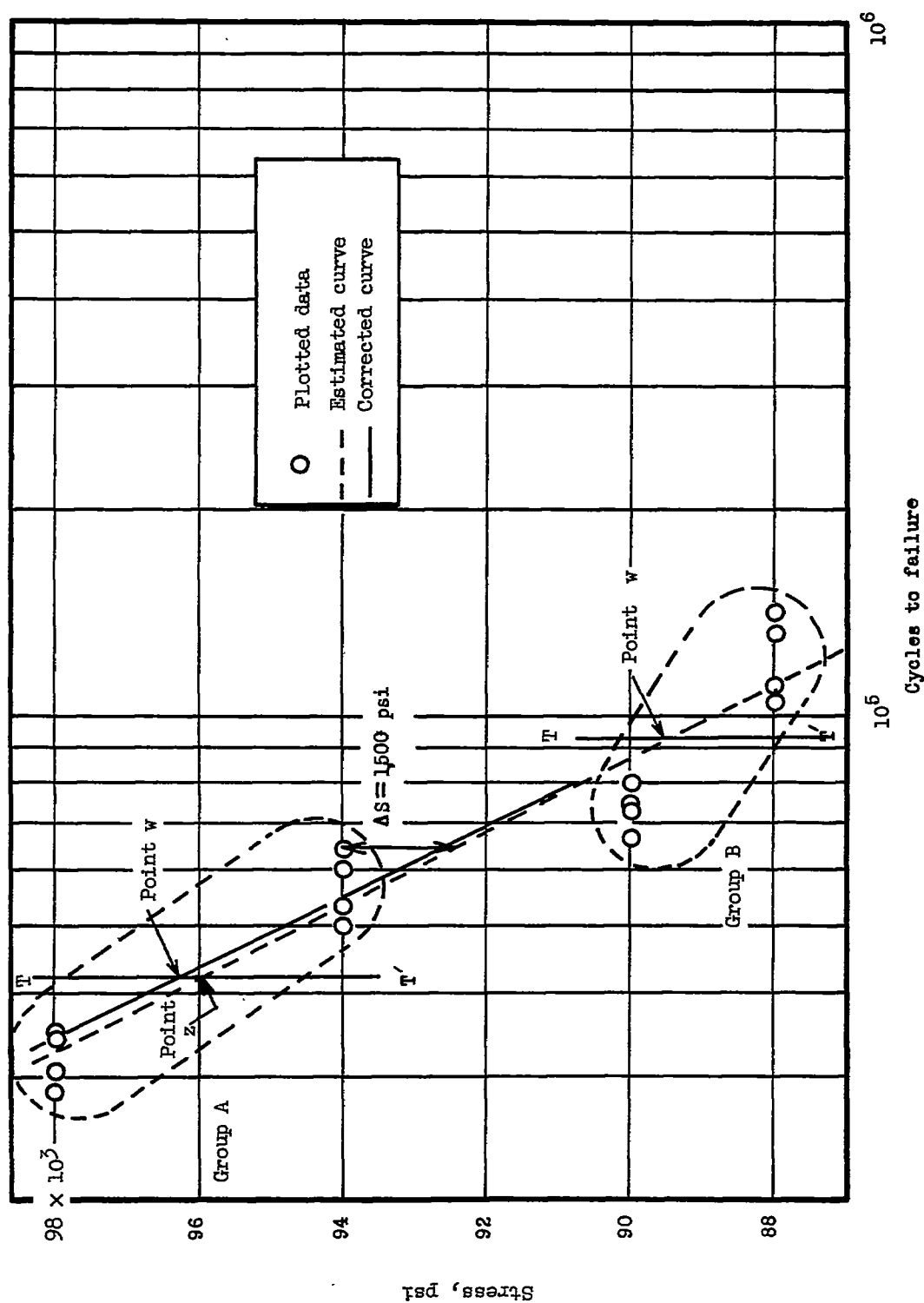Figure 4.- S-N curve at room temperature.

Figure 5.- S-N curve at 400° F.

Figure 6.- S-N curve at 800° F.

Figure 7.- Determination of mean curve.